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Enhancing The Functionality of Traditional Interior Textiles with Integration of Optical Fibers

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ABSTRACT

The colors of traditional interior textiles cannot be changed. With the development of hi-tech textiles, interior textiles and furnishings with changeable colors are now possible with the integration of optical fibers. In this article, a study on the design of optical fiber integrated photonic interior furnishings is presented. First, the applications of polymeric optical fibers (POFs) in textiles are reviewed. It is observed that although there have been a wide variety in applications of POFs in textiles, research on the application of POFs in interior furnishing is rarely reported. The gap between technology and design handicaps the usability of photonic products. In order to design user-friendly photonic soft furnishings, a new design method is explored. Both technical and design aspects are considered in the development of photonic soft furnishings. A prototype of photonic fabrics and soft furnishings is successfully created. A usability test is undertaken to evaluate the performance of the prototype. The result of the usability test reveals that most of the subjects are satisfied with the overall performance of the prototype. They believe that photonic interior furnishings with changeable colors can enhance the environment. These usability test results are fed back to the design framework, and can provide a good source of reference for the improvement of photonic soft furnishing in the future.

Keywords: Photonic Soft Furnishing, Textile Design, Polymeric Optical Fiber Fabric, Illumination

1. Introduction

Nowadays, as living spaces are becoming smaller and people have more diverse activities within compact spaces, there is a growing demand for flexibility in the interior environment. Consumers are requesting interior textiles that are multifunctional, reactive and interactive (Nielson, 2007). Interactive interior textiles enable individual users to interact with the interior and flexibly customize their fixed interior surroundings for different purposes. Interactive interior textiles are especially relevant to densely populated cities like Hong Kong whereby most of the population live in compact spaces.

With the emergence of polymeric optical fibers (POFs), textiles engineered with the ability to interact with the user as well as other surrounding technology are now possible. Photonic textiles with interactive functions that change and tune color can present pleasing visual effects and customize and enhance the interior environment.

This article reports a study on the development of user-friendly photonic soft furnishing by using polymeric optical fiber fabrics (POFFs). First, the applications of POFs in textiles are briefly reviewed. Then, the technologies involved in the development of POFFs for interior textiles are introduced. Finally, a usability test is carried out to evaluate a photonic soft furnishing prototype.

2. Applications of POFs in Textiles

2.1 POFFs for Illumination and Fashion Accessories

The history of photonic textiles based on POFs

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started in the late 1960s, when DuPont was investigating the field of optical polymers and fiber production. Since then, some of the fashion, design and architecture products that employ luminous fabrics are commercially available in the market. In most cases, a multiplicity of polymer optical fibers are integrated into textile structures connected to a light source on the fiber ends.

2.1.1 Clothing and Accessories

An optical fiber display (Koncar, 2005) which integrated optical fibers, that is, light emitting diodes (LED)s, into a jacket to create a textile screen (Figure 1) has been reported. The technology is based on woven POF that have cladding imperfections (mechanical, thermal, and chemical damage) and therefore light emitting sites.

Fig. 1. Optical fiber display

Illuminated curtains and light generating fabrics for clothing or accessories (Figures 2 and 3) have been produced as woven and embroidered structures by using larger POFs (diameters from 0.25 to 0.75 mm) (www.itp-gmbh.de). Time Magazine (Clayton, 2006) announced a light-radiating 'fabric' made from slender fiber optic cables to create glittering objects, as well as curtains and wall hangings made by Torbjörn Lundell (www.glofab.se). Enlightenment accessories are especially useful in poorly illuminated or non-illuminated locations.

Fig.2. Illuminated bag with solar module

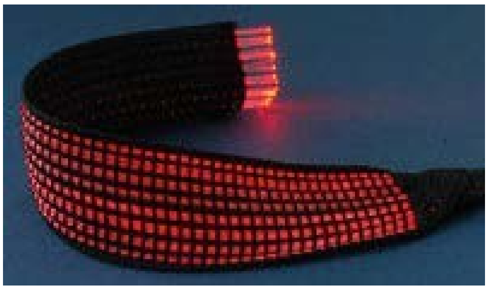

Fig. 3. Optical fibres woven into belt

2.1.2 Interior

Although POFFs used in clothes with a reasonable light emission are sturdy and considerably robust in structure, POFFs with integrated POFs that have thicker diameters seem to be more suitable for interior and industrial art applications, public premises, vehicles, and other related applications (Harlin et al., 2003). Creative luminous POFFs have been designed in large scale for ambitious indoor lighting (Harlin et al., 2003, http://www.luminex.it) (Figure 4), and further applications in transport systems and communication (www.brochiertechnologies.com) (Figures 5 and 6).

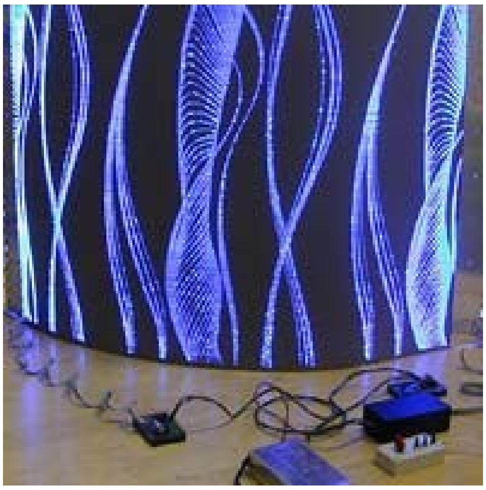
Fig. 4. POFFs for indoor lighting


Fig. 5. Illuminated strip in a seat


Fig. 6. Illuminated seats in a railway carriage

Based on the literature review, it is identified that there are still many challenges in the design of POFFs for interior textiles because:

a) it is more difficult to weave and knit POFs than ordinary yarns due to their rigid nature,
b) the final products should be mobile, durable, safe, and therefore the electronics are required to be smoothly and unobtrusively integrated into textiles, and
c) the seamless integration of electronics into photonic textiles to evoke interaction of the textiles with the user and the environment still needs to be further improved.

2. Design Method

Most photonic textiles for illumination are developed by academics from scientific disciplines, such as electronics and photonics, and the developed prototypes often lack aesthetic and design. Little work has been conducted from a fashion designer's perspective. On the other hand, most designers have insufficient technical knowledge, which may handicap the development of hi-tech textiles. The key issues are that the conventional structure of new product design models would fail to demonstrate the different work methods of the two sectors, technologies and design. Thus, a new product design model is needed to enhance the understanding on the work and communication between different disciplines.

Baurley (2005) suggests a design methodology for the interactive design of smart clothing. The methodology consists of a conceptual framework, user study, and design building. The framework is based on observations and research on how people use, interact with and experience conventional clothing. The user studies are based on user groups and are again fed back into the framework.

In another literature item, the "Critical Path" was proposed, a design tool that guides the design research and development process in the application of smart technologies (McCann et al., 2005). A design tool was developed to support innovative decision making in the sourcing and selecting of appropriate materials, technologies, and construction methods. The process included identification of end-user needs, fiber and fabric development and textile assemblies, and garment development. To maintain a balance in appearance and function, designers require guidance in their selection and application of technical textiles, style, cutting, sewing, and finishing at every stage in the design research and development process.

The two design methods above facilitate the design of smart textiles and clothing. There is a lack of methodology, however, in the design of photonic soft furnishing. This research attempts to investigate and develop photonic interior textiles for soft furnishings with integrated POFs from both technical and design aesthetic perspectives. A new design framework for the design of photonic soft furnishing is proposed (Figure 7). Traditional fashion design methods and textile technology are used in combination with modern technologies throughout the entire process of development.

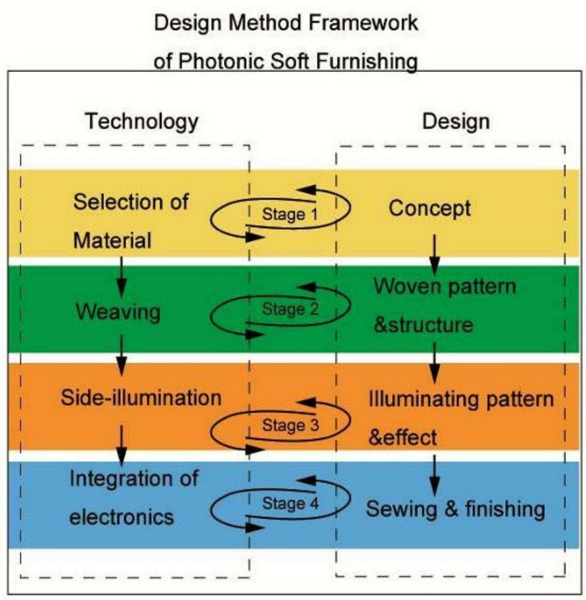

Fig. 7. Design method framework

In the new proposed design framework, every stage is an interactive process between technology and design. The development of one part will simultaneously affect its counterpart, and therefore the development at every stage is a continuous process. For instance, in stage one, the selection of material should express the design concept, and the design concept should also consider the characteristics of the selected materials, such as the features of optical fibers. In stage two, traditional weaving should follow the weaving pattern and structural design, while the design of the woven pattern and structure should take into account the technical issues of weaving optical fibers into a piece of fabric. Design work needs to be continuously revised in accordance with experiments on the prototypes. In stage three, the side-illumination of optical fiber fabric is achieved by laser-engraving technology. The technical and design aspects should work very closely to successively improve the illuminating effects. In stage four, integration of electronics brings great challenges to sewing and the finishing process. Innovative sewing and finishing methods should be developed to meet the special requirements of embedded electronics. Unobtrusive appearance and durability should also be considered when developing electronics.

3.1 Textile Processing of POFFs

Weaving technology is adopted for integrating POFs into textiles in this research work due to the fact that the grid structure of the weave is advantageous as it allows exact fiber arrangement and position determination (Abouraddy et al., 2007). In this study, plain weaving and jacquard weaving are adopted to manufacture the photonic fabric. Photonic fibers were introduced as weft yarns, while warp yarns were cotton threaded. By varying the weave structure and incorporating photonic luminescence generated by the integrated photonic fibers, different surface patterns, textures, colors and lusters can be created. A Dornier weaving loom and Staubli Jacquard head were adopted for the production of optical fiber fabric (Figure 8). Figure 9 shows a photonic fabric prototype with a geometric jacquard pattern.

Fig. 8. Optical fiber integrated fabric that is being processed on a weaving jacquard loom

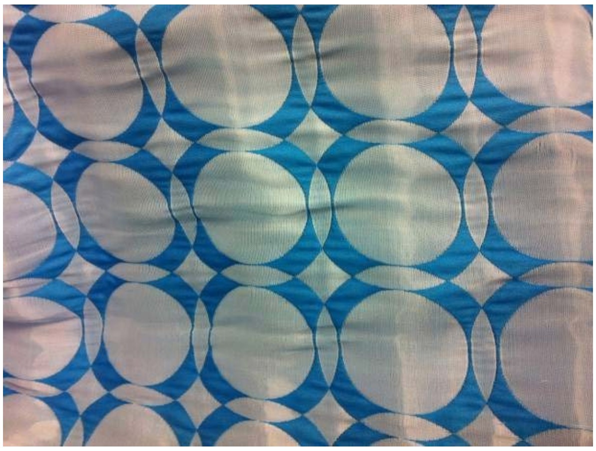

Fig. 9. Optical fiber fabric with geometric jacquard pattern

3.2 Side-Illumination of POFFs

The main role of photonic fibers is to transmit light or optical signals to a specified spot. However, if the cladding of the photonic fiber is partly damaged by physical or chemical treatments, the light leaks out from the damaged area and side-lighting will occur. Side illumination of fabric will greatly enhance the surface color and pattern especially in dark environments.

In this research, laser engraving is employed to induce lateral emission of light. Laser engraving is a technology that uses a high-power laser to cut materials, and the engraving can be precisely controlled by a computer. A laser engraving machine (GFK Marcatex Flexi-150) was utilized. The fabric was placed onto a platform, and a laser was directed onto the fabric surface. The predefined engraving pattern was achieved by repeated laser scanning across the fabric surface. By altering the resolution (in dpi) of the designed pattern and the pixel time (in μs) of the laser radiation, different engraving parameters can be achieved across the fabric surface and photonic fibers were damaged to different extents, and therefore different side-lighting effects of the photonic fibers were realized. The engraving process was accurately controlled by a computer programme.

3.3 Integration of Electronics

Depending on the application of the POFFs, various light sources can be connected to optical fiber ends. Bright LEDs (Graham-Rowe, 2007) have been used for photometric applications and radiometric purposes.

For the design of photonic interior textiles, the usability of the final products needs to be considered. It is very important that the electronics, which include light sources and control devices, are unobtrusive. In addition, most of the interior products need to be lightweight, durable and mobile, and therefore powerful laser light sources are not suitable for this kind of application. In this study, small LEDs with RGB colors are used as the light source in order to produce mixed colors (Figure 10). LEDs with RGB colors can generate different colors as required, and a color can be changed and tuned by fine-tuning the primary colors. Groups of photonic fibers were bundled together and then coupled with LEDs that have predetermined sequences.

An ultraviolet bonding technique was adopted in coupling LEDs, which can maximize lighting efficiency and reduce coupling loss. LEDs were connected with a branch of optical fibres by using NORLAND 65 optical adhesive. All controlling electronics of LEDs were docked in a motherboard.

Fig. 10. Illuminated effect with integration of LEDs

4. Usability Test

In order to test the usability of the photonic soft furnishing, a questionnaire was conducted to analyze the user's experience with the prototype.

Fifty subjects took part in this questionnaire. They are 20 to 25 year old college students who are in the fashion design discipline. Among them, 17 are male, and the other 33 are female. “Chinois Photonics”(Bai et al., 2011), a collection of soft photonic furnishing, was evaluated (Figure 11).

Fig. 11. Photonic cushion

“Chinois Photonics” was inspired by ancient Chinese pottery. The design attempts to interpret the colors and patterns of ancient painted pottery from a contemporary perspective. A series of earth-tone cotton fabrics and yarns were selected. Printing and embroidery on the surface of photonic cushions can enhance aesthetic attractiveness as well as hand feel. Rechargeable batteries are hidden inside the foam of the cushion, so that the cushion is movable. Users can hug, sit against and play with the photonic cushion just like other normal cushions. In the dark, strong block colors are illuminated from the textiles, providing a stark contrast to the daytime version.

Fig. 12. User experience investigation

Prior to conducting the questionnaire, basic knowledge on photonic textiles and the design method of the final product were introduced to each subject (Figure 12). The investigator observed the subject’s behavior while s/he was using the product. After that, a questionnaire was carried out with each subject.

The questionnaire consisted of two parts. In the first part, the respondents were asked to rate the performance of the prototype according to a seven-point scale. As color, appearance and hand feel are some of the most important aspects of textile quality, and these properties constitute the primary elements that drive consumers to purchase textile products, the respondent was asked in the first part of the questionnaire to evaluate the performance of the prototype by rating different aspects of a photonic cushion with a Likert scale, including original color of fabric, color of photonic fabric, appearance of printing, appearance of embroidery, shape, hand feel and illumination (Table 1).

Table 1. Assessment items for cushion performance

	Unsatisfactory	Very Satisfactory
Original color of fabric	1 2 3 4 5 6	7
Color of photonic fabric		
Printing appearance		
Embroidery appearance		
Shape/silhouette		
Hand feel		
Illumination (lighting)		
Original color of fabric		

The Likert scale was used to rate each aspect of the cushion performance, from 1 (very unsatisfactory) to 7 (very satisfactory). The overall rating was obtained by taking the average of the ratings from all respondents. The second part of the questionnaire included a series of questions, such as "Do you agree that the photonic cushion can enhance the interior environment?", "Is it convenient to use the photonic cushion?", etc. These questions were designed to evaluate the performance of the photonic cushion from both technological and aesthetical aspects.

5. Results

A quantitative analysis was performed for the first part of the questionnaire, and the average ratings of all the performance items are listed in Table 2.

Table 2. Overall rating of performance

Performance	Overall rating
Original color of fabric	4.28
Color of photonic fabric	4.3
Printing appearance	4.26
Embroidery appearance	4.14
Shape/silhouette	4.32
Hand feel	4.06

Table 2 shows that the overall ratings of all the performance items are above four, which indicate that the overall performance of the photonic cushion is satisfactory. It can also be observed that the hand feel rating is slightly lower than the other items. This could be attributed to the rigid nature of the POFs when they are integrated into the cushion.

When asked "Do you agree that the photonic cushion can enhance the interior environment?", 54% of the respondents agreed and 24% strongly agreed (Figure 13). This result reveals that photonic soft furnishing can definitely enhance interior ambience with its unique function and appearance.

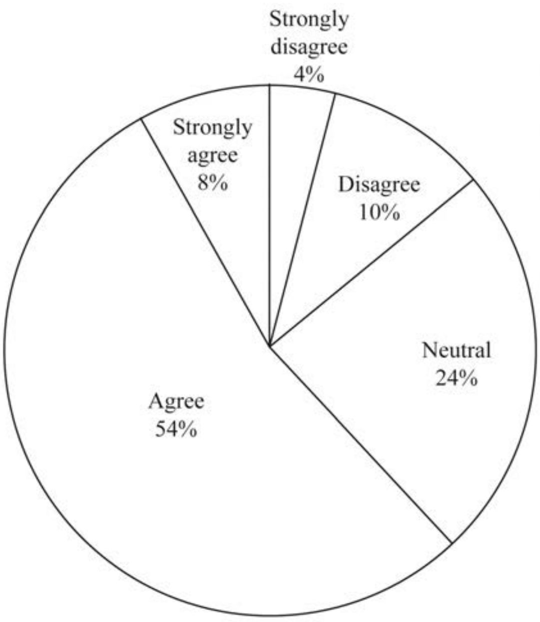

Fig. 13. Responses to "Do you agree that the photonic cushion can enhance the interior environment?"

It is very important that a hi-tech product is easily operable by end-users who have little technical background. In the second part of the questionnaire, the ease of use of the prototype was assessed. The respondent was asked: "Is it convenient to use the photonic cushions?", and 12% of the respondents chose "convenient", 54% indicated that it was "acceptable", while around 20% recognized that it was not convenient because the batteries need to be recharged or replaced (Figure 14). The power supply seems to continue to be a significant challenge to the development of photonic furnishing.

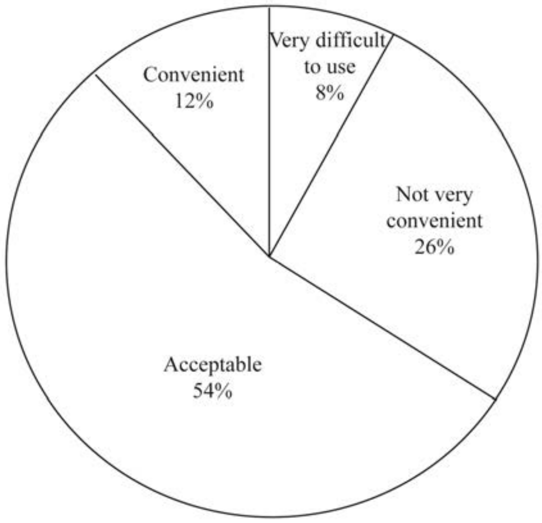

Fig. 14. Response to question- "Is it convenient to use the photonic cushion?"

The photonic cushion has an illumination feature, which tradition interior textiles do not have. Figure 15 shows that a total of 70% of the respondents appreciate this novel technology of illuminating, and consider this new feature of photonic interior textile to be more attractive than the general properties of traditional textiles, such as color, material and hand feel. This result indicates that the photonic property obtained by the integration of POF can improve the attractiveness and function of traditional interior textiles.

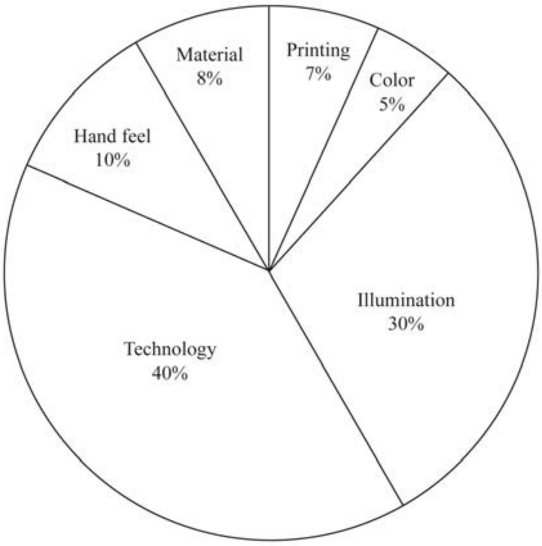

Fig. 15. Response to question- "Which feature do you find most attractive in the photonic cushion?"

6. Conclusion

This article reports a study on the development of photonic furnishing with integrated optical fibers. A design framework was developed, which attempts to embrace both technical and aesthetical concerns. Optical fibers are introduced into fabric by jacquard weaving. LEDs are coupled at the fiber ends as the light source, and laser engraving is employed to provoke side illumination. The performance and usability of a developed prototype are evaluated by a focus group. The results indicate that the overall performance of the prototype is satisfactory, and photonic furnishings are considered to have the ability to enhance the interior environment. The result of the questionnaire also reveals that the functionality of traditional interior textiles can be improved with the integration of POF. The respondents have also suggests that the power source needs to be improved, which constitutes the framework for future studies.

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