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Master's Thesis
Academic Year 2021

Smart Textile Using 3D Printed Conductive Sequins

Keio University
Graduate School of Media Design

Hua Ma

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

Hua Ma

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Abstract of Master's Thesis of Academic Year 2021

Smart Textile Using 3D Printed Conductive Sequins

Category: Design

Summary

In this study, I propose the design and implementation of a smart textile using conductive sequins produced by a 3D printer based on traditional sequin embroidery.

The well-designed conductive sequin smart textile, which is referred to traditional sequin embroidery of myriad designs and diverse embroidery techniques, is able to break through the limitations of sequin fabric in its vertex modeling capability to create vertex-like sequins.

Using conductive and non-conductive resins, I printed out two types of sequins using a 3D printer[1], which are then combined and embroidered using the traditional sequin embroidery technique. When a force such as touch or press is applied to the conductive sequins, a signal generated from the circuit, which those sequins themselves are are part of, will be sent to the computer. The computer can then visualize the electric signals of this textile and sense the changes in the state of the textile.

By combining conductive and non-conductive sequins, the sensing area can be separated automatically while applying patterns of sequin embroidery. The range and accuracy of sensing varies depending on the shape, size, and embroidery of sequins, while the manner of expression of visualization data is expected to change in accordance with the user's desired use and design. By utilizing this smart textile, not only for clothing, but also for space production, education, etc., I will explore a new way of communication between oneself and the world by recognizing the relationship between the body and the environment more deeply.

1 `https://flashforge.jp/product/adventurer3/`

I will combine the decorative function of traditional sequin embroidery fabric with smart function through conductive material. Using the characteristics of conductive sequin and traditional embroidery method, I expect to discover a new pattern design of conductive sequin, so that ordinary users can also make smart sequin fabric and clothing with their desired smart function according to our design guidelines.

Keywords:

smart textiles, conductive material, sequins embroidery, data-input device, wearable device, sensing platform, interactive textiles

Keio University Graduate School of Media Design

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Chapter 1
Introduction

1.1. Context

1.1.1 The popularity of smart wear for integrated circuits and its limitations

Nowadays, with the development of 5G technology and XR technology, the connection between the real world and the virtual world will become more and more tight. Some common electronic devices and technologies, such as augmented reality function in smart phone or tablet, VR glasses, smart watch, smart glasses, etc., are all attempts to connect the real world and the virtual world. With the introduction and development of the metaverse[1] concept, it is reasonable to imagine that the future will be a kind of hyper-composite world in which the real world connects multiple parallel virtual worlds, and with the spread of the COVID-19 epidemic now, more and more social activities and work have been passively or actively online. And as the 2 years of the epidemic continues, an online plus offline composite way of living and working is now gradually derived, and people are gradually adapting to the existing state of living and working while putting forward new requirements for communication, interaction, and production in the virtual world. I believe that in the post-COVID-19 era, we will establish more living and working spaces in the virtual world to expand the upper limit of human communication and interaction space. And this requires more intimate, more flexible, and more adaptable to daily life transmission devices and platforms that can accommodate more functions to help us sense the existing physical state and environmental state, and establish more realistic and efficient interaction and

1 `https://en.wikipedia.org/wiki/Metaverse`

(a) Jacquard by Google (b) Nadi x Yoga Pants (c) Sensoria Fitness Socks

Figure 1.1 Smart wears

communication in virtual and reality.

As our second skin, clothes can be almost the most indispensable item in our daily life. Clothes cover our bodies and can fit perfectly into our daily life. It does not add extra burden to us than mobile phones, watches, VR glasses, etc. It can be worn more naturally and can sense our movement status and physiological signs more directly and in a larger area.Smart wearables can be defined as electronic devices intended to be located near, on or in the body to provide intelligent services that may be part of a larger smart system thanks to the use of communications interfaces.Smart clothes can be created by embedding smart wearables into garments [2].

There are many kinds of smart clothes being developed now, and some of them are already available as commodities for the general public. For example, Jacquard by Google[2] connects to your smartphone via Bluetooth and can screen phone calls, control music volume, and notify you when your rideshare is nearby, Nadi X Yoga Pants[3] can sense when your yoga pose needs refining. Using haptic feedback, the smart pants create small vibrations on the body part you need to adjust, Sensoria Fitness Socks[4]use advanced textile sensors built into each sock, plus a Core device that snaps into the dock that is attached to the sock to deliver precise data on how your foot lands while walking or running.

2 `https://www.levi.jp/2019aw_googlejacquard.html`

3 `https://www.wearablex.com/collections/nadi-x-smart-yoga-pants`

4 `https://store.sensoriafitness.com/sensoria-core-pair/`

Although many smart garments have been developed, the development of smart accessories for smart garments is not perfect due to the mismatch between electronic components and garment characteristics, so there are still many limitations.

- Need additional electronic components.
- Washing problems.
- The textile becomes thicker and uncomfortable to wear.
- Low durability, easy to damage.

1.1.2 Example of HCI research on smart textiles and its limitations

Example of HCI research on smart textiles

In order to solve the above problems, many researchers have started to integrate electronic components as well as smart accessories into garments in a more fitting way from the materials used to make the garments.

And smart textiles are the base material of future clothing. Its flexible qualities and potential to carry functions over a large area can be used as a smart new material in the fields of clothing, households, and intelligent robots.

Many studies have been proposed to add functionality to cloth by using conductive materials: conductive inks [3], conductive rubbers [4], and conductive tapes [5]. These materials can all be combined with a cloth to detect the user's movements since they are flexible conductive materials that can be stretched; however, they are easily peeled off or limited to flat shapes.

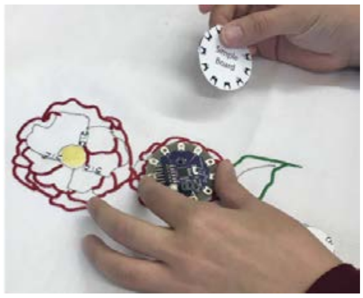
On the other hand, there have been several proposals to use conductive threads woven into a textile as sensors [6–10], which have the advantage of manufacturing complex shapes quickly because they are made using embroidery sewing machines. However, these objects are commonly limited to flat-shape circuits and are challenging to create three-dimensional functional structures.

The industry has also emerged other proposals of smart materials and applications. There have been efforts such as attaching 3D printed materials to cloth [11], but this time I decided to use conductive materials to create a functional textile.

(a) Adapting Double Weaving and Yarn Plying Techniques for Smart Textiles Applications

(b) ModiFiber: Two-Way Morphing Soft Thread Actuators for Tangible Interaction

(c) KnitUI: textileating Interactive and Sensing Textiles with Machine Kniting



(d) Sketch & Stitch: Interactive Embroidery for E-Textiles

Figure 1.2 Example of HCI research on smart textiles

Topographie Digitale [12] pleated conductive ink-soaked textile to create stretchable sensors, Wearable Bits [13] uses patchwork techniques to design customizable textile circuits, and SensorSnaps [14] allows its users to manipulate the interface using microcomputer-embedded snaps. There are also examples of using zippers to create various deformable shapes [15]. In contrast to these examples, the use of sequins can lead to new input interactions by incorporating the unique color changes and tactile sensations of sequins.

Most of the related research is based on the existing textile manufacturing process, by embedding or coating some conductive, deformable, or color-changing materials, and then modifying and updating the existing process, so as to give the textile sensing or output performance and other intelligent functions. I think this is a very practical way, and because of the richness of existing processes and the diversity of new materials, this can not only broaden the application field of new materials but also have a very positive role in promoting the inheritance and evolution of traditional crafts.

limitation

Although smart textiles have different characteristics, they have the following limitations when considered collectively.

- Expression is concentrated on flat surface, less tactile expression.
- The weaving method such as sewing and weaving determines that it is less forgiving.
- Need to use special machines such as sewing machines to ensure its production efficiency and accuracy as well as the overall aesthetics.
- The use of some intelligent materials is too special, which makes it more difficult to integrate the process.

1.1.3 Technology and fashion

The main reason why the above problem occurs, I think, is that in addition to having the characteristics of fit, flexibility and natural wear, clothing also has a very important characteristic - fashion. While satisfying functionality, clothing is also an important platform for expressing our personality, emotions and aesthetics. Therefore, when designing and developing smart textiles, we should also take into account its requirements for fashion and aesthetics.

For the smart textiles developed now, the answer to this question is mainly to make the devices carrying smart functions as small, thin and flat as possible, so that they can be hidden in the garments, and the main design concept is not to hinder the fashion design. However, for the individual expression of clothing, these design spaces limited to flat surfaces are far from enough.

However, with the development of the virtual digital world and the popularity of intelligent life, the functions that need to be carried by garments will become more and more complicated, and the complexity of wiring will gradually increase, and the requirements for technology will become higher and higher.

Therefore, how to create more design space for the implantation and appearance design of smart devices in existing textiles at the same time, I think this is a very tricky problem but with a lot of research space.

I think the first thing is to break the existing textile and garment structure, that is to say, to fundamentally free the design space. Compared with the traditional hidden and embedded smart textiles and garments, how can we cleverly connect ordinary textiles and smart originals through the combination without destroying the aesthetic premise, it may greatly increase the possibility of smart garment(Fig.1.3)s.

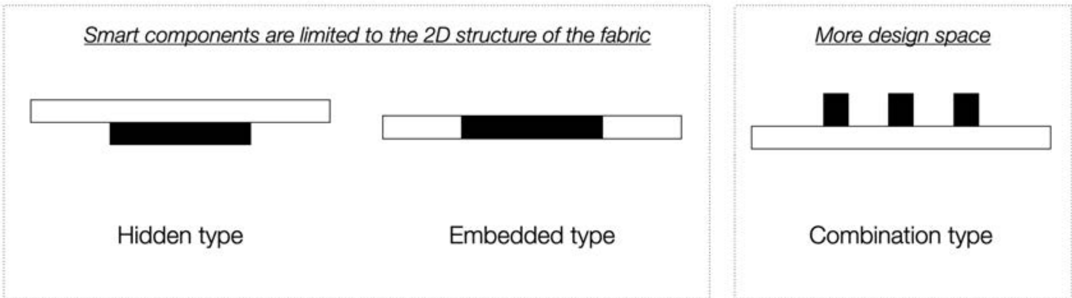
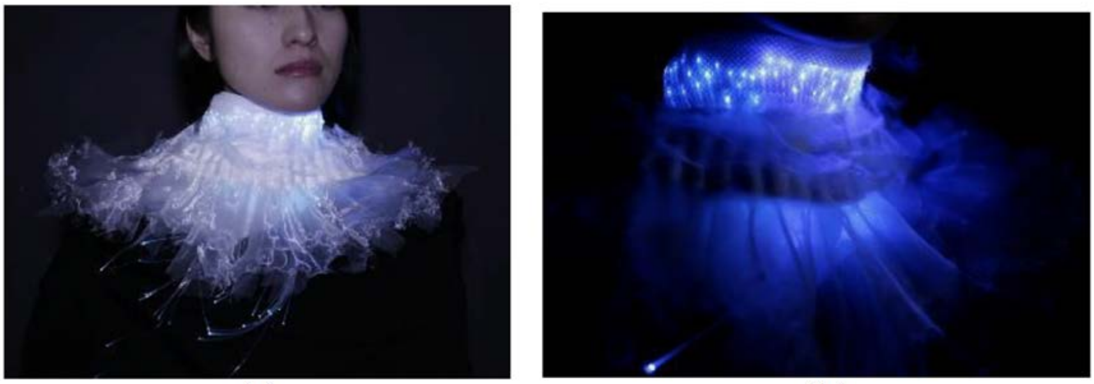


Figure 1.3 Break the traditional smart textile design space

In fact, there are already many designers who have made bold attempts in garment construction, for example, bioLogic [16](Fig.1.5) deforms garments through sweat, Wearable Forest [17] interacts with nature through audio devices inside garments, Aerochromics[5]on the garment pattern displays detected air pollution, Bio-Collar [18](Fig.1.4) installs smart, actuatable hairs on clothing that express physical signs of human.

5 https://fashioningtech.com/2016/08/17/aerochromics-pollution-monitoring-garments-aim-to-become-a-sixth-skin/



(a) (b)

Figure 1.4 Bio-Collar

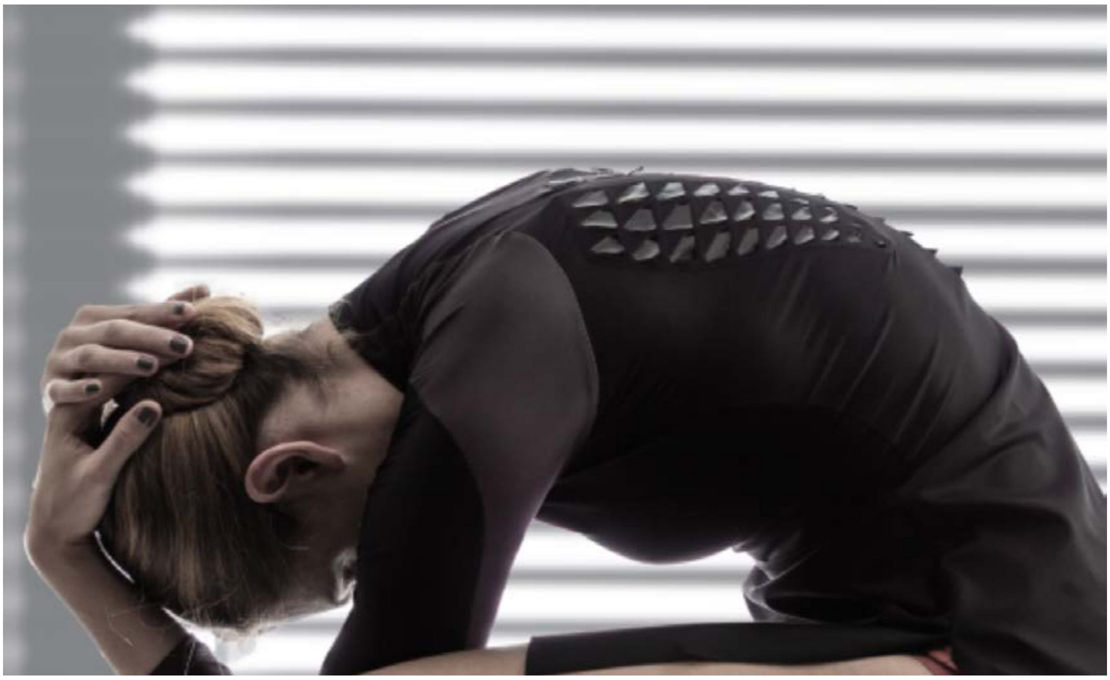


Figure 1.5 Biologic

1.1.4 Conductive sequin embroidery smart textiles

Sequin embroidery textiles

Sequin embroidery – a traditional embroidery technique – has wide use in textile manufacturing. By changing the sequins' size, shape, color, arrangement, and embroidery, we can obtain the various type of sequined textiles. For example, the two sides of the sequins can be dyed in different colors, specific sewing techniques can fix the direction of the sequins, and multiple patterns can be drawn by flipping the sequins. Depending on the material, most of the sequins can reflect star-like glory, provide a comfortable touch different from other textiles because of the regular arrangement, and even make a sound with human body movements(Fig:1.6[6]).

Figure 1.6 Garment with sequins embroidery: Givenchy haute couture, fall 2019

6 `https://www.nytimes.com/2019/07/03/fashion/givenchy-margiela-armani-giambattista-valli-couture-fall-2019.html`

Figure 1.7 Sequins embroidery textile

Although the design process of sequins usually allows a wide spectrum of materials to explore, most of the sequins are still cut from vinyl plastic sheets; hence their final shape is still limited to flat surfaces. However, with the development and popularity of 3D printing technology, more three-dimensional shapes of sequins can now be made with 3D printers to enhance the design dimension of smart textiles from two-dimensional to three-dimensional, which can later be turned into intelligent sequins via conductive materials.

Traditional sequins embroidery technique

Traditional sequin embroidery is divided into two main categories, one is embroidery with only sequins and the other is embroidery with the beads. In this article, we will only discuss the pure sequin embroidery without beads.

With a bead embroidery needle, stitch from the outside of the sequin to the center hole(Fig:1.8).[7]

Stitching at the length of the sequin radius gives the appearance of overlapping sequins by half(Fig:1.9).[8]

Smart textile using 3D printed conductive sequins

To break up the existing textile structure, I chose to base on sequin embroidery textile among many textiles.

The design of garment textile reconstruction, as the name implies, is to recreate and redesign the texture, color, pattern and other observable external features of the textile to match the style of the garment design, as well as to reinforce the uniqueness of the brand. textile redesign reinforces the important role of textiles in fashion design, while enriching the design process. Textile reconstruction allows designers to use more creativity and possibilities in their designs, therefore fostering more diversity and imagination in the world of fashion design. [19]

The essence of sequin textile is textile redesign. The purpose of textile redesign is to recreate the look and feel of textile by means of design and craftsmanship in order to enhance its intrinsic beauty. In other words, it was created to increase

7 `https://petitemercerie.com/?mode=grp&gid=2562514`

8 `https://petitemercerie.com/?mode=grp&gid=2562514`

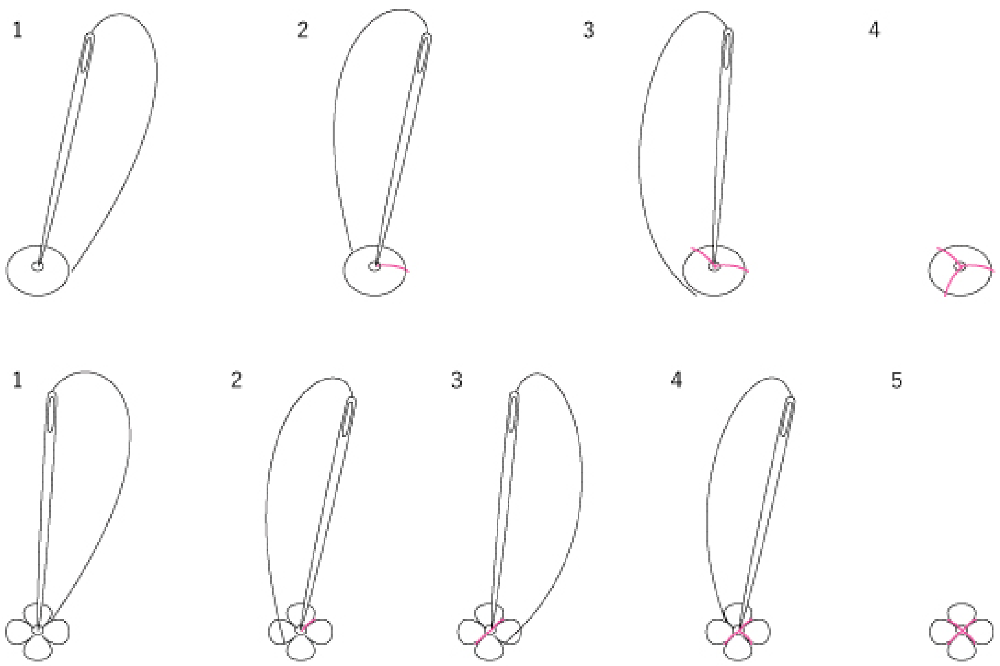


Figure 1.8 How to sew on sequins one at a time.

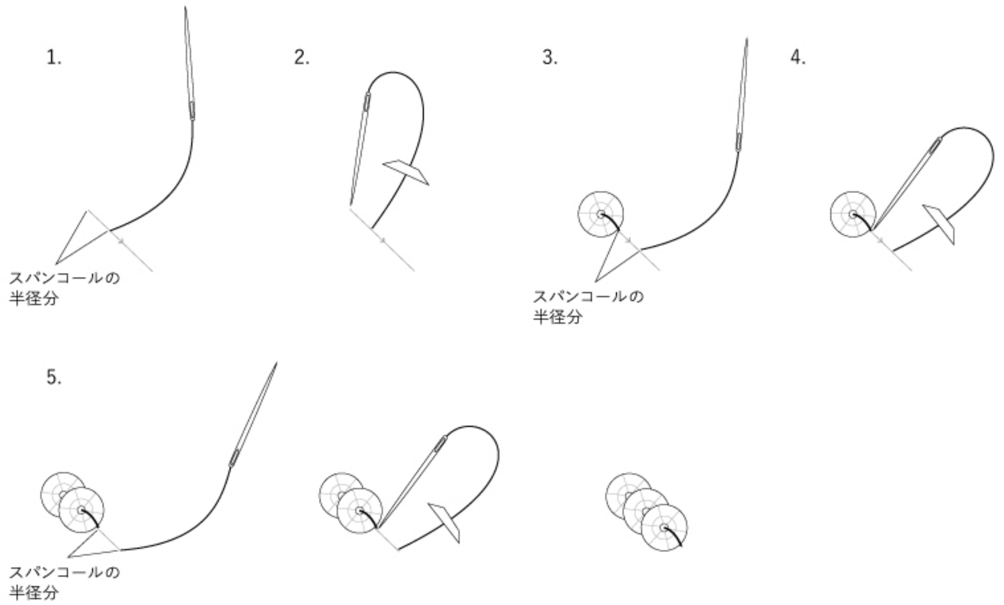


Figure 1.9 How to sew sequins in a continuous half layer.

the design space of the textile. So as an expansion of this function, we can add design space to the textile with smart functions by adding conductive sequins to the current base.

Through 3D modeling we can get sequins of any shape and size we want, then use conductive materials to print them out through a 3D printer, and then use materials such as conductive sewing thread to achieve smart functions through simple sewing. The design process of sequins and the overall textile combination process allow us to get a very large design space, which is very beneficial for both fashion design and technological elements implantation.

The conductive sequin embroidered smart textile has the following features that distinguish it from other inline smart textiles(Table:1.1).

- Semi-dimensional structure : 2.5D design with special touch.
- Combined structure: composed of textile and sequin combination, giving more space for circuit design of smart elements.
- Independent unit: good repair, good replacement, easy to customize.

- Manufacturing difficulty: easy to sew.
- Special double-layer structure: base textile + sequins can release the design and configuration space of electronic components.
- Highly interactive: with flip sequins and other interactive ways(Fig:1.10).

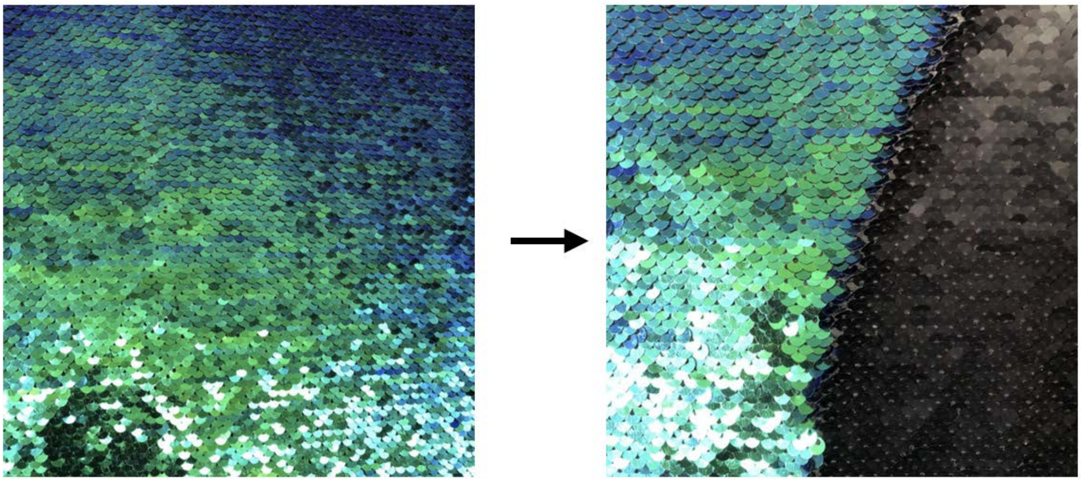


Figure 1.10 Flip sequins embroidery.

1.2. Research goal

1.2.1 Research question

In response to the above-mentioned contradictory points and possibilities between fashion and technology, I have the following two questions about the future of the smart textile field.

- Is it possible to modularize the smart textile, and freely configure the sensing and other smart functions carried by the textile by adjusting the material and structure of the surface of the textile?

	Hidden Type	Embeded Type	Conductive sequin (Combination Type)
Design Space	2D	2D	2.5D
	1 Function ⇊ N Designs	1 Function ⇊ 1 Design	1 Function ⇊ N Designs
Aesthetics	⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆
Comfort	⋆ ⋆	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆
Tactility	⋆	⋆ ⋆	⋆ ⋆ ⋆ ⋆ ⋆
Manufacturing fault tolerance	⋆ ⋆ ⋆ *Replaceable*	⋆ *Hard to modify*	⋆ ⋆ ⋆ ⋆ *Individual, replaceable*
Manufacturing Simplicity	⋆ ⋆ ⋆	⋆ ⋆	⋆ ⋆ ⋆ ⋆ ⋆
Expansibility	⋆ ⋆ ⋆ *For specific needs*	⋆ *For specific needs*	⋆ ⋆ ⋆ ⋆ *For various structures*
Interactivity	⋆ *Fixed structure*	⋆ ⋆ *Fixed structure*	⋆ ⋆ ⋆ ⋆ ⋆ *Flexible structure*

Table 1.1 6 Sections of Experiments

- Is it possible to design a smart textile that can break the existing garment structure and create a new garment form that can adapt to the future "reality + virtual life" with an overall appearance design oriented to technological needs?
- Is it possible to provide fashion designers and handicraft enthusiasts with a design method and idea to guide smart functional design by appearance, in order to improve creators' enthusiasm and creative ability for smart clothing or smart textiles?

1.2.2 Research Goal

To answer these two questions, the goal of this research is

- to design and explore the characteristics and textileation process of conductive sequin embroidery and to find design methods to achieve various sensing functions by adjusting the material and surface structure of sequin embroidery.
- And to summarize a set of design principles and design methods for fashion designers and handicraft enthusiasts with a large degree of design freedom. Thus, I will explore new forms of future smart textiles and the potential of smart textiles using 3D printed conductive sequins in the future fashion and technology industry.

1.2.3 Proposal

This research proposes a smart textile using conductive sequins produced by a 3D printer with a data input function.

Touch input and shape recognition can be reached by touching, pressing, or flipping the conductive sequins. Sequins movement and collision can be triggered by human action and environmental changes such as natural wind, the input of which will later be sent to the computer and visualized.

In detail, we design the desired shape of the sequins, 3D print them with conductive filament, and then sew them to the regular textile with standard sewing thread. The conductive sewing thread is used to connect two or more of the sequins to the power supply. Similar to the function of a switch, the conductive sequins touch each other to generate electrical signals and input them to the computer through an Arduino Uno board[9]. We can delineate the controllable area by adding non-conductive sequins 3D-printed with PLA Filament to the conductive sequins embroidery textile. The circuit is designed by combining two types of sequins. By adjusting the shape, size, texture, and embroidery method of the sequins, we can change the softness, resistance value, and bistability of the textile.

We designed and printed many distinct kinds of conductive sequins, made them into small samples of conductive sequins embroidered textile, and installed them into the circuit for testing. In addition to the test, I made a garment with the smart textile and used it in a performance. In this research, I will discuss the design process, the trial experiments of various conductive sequins and the use cases.

1.3. Structure

This thesis will be divided into six chapters. In the first chapter, I will introduce the background and reasons why conductive sequin embroidery is the object of study and the reference value of traditional sequin embroidery techniques. In the second chapter, I will introduce the position of conductive materials in the development process of smart textiles and the current attempts of smart textiles in the field of fashion technology.

In the third chapter, I will explore the properties of conductive sequin embroidery textiles and explore their design space through two prototypes and one workshop, which will be the premise and foundation of the whole research. Using the design primitives and characteristics of conductive sequin embroidery textile summarized in chapter 3, I will apply it to garments in chapter 4. Through the production of two applications and user interviews, I will verify the feasibility of our proposal in chapter 5 and discuss its contribution and limitations respectively.

In Chapter 6, O summarize the existing findings and plan the next step of

9 `https://www.arduino.cc/en/Guide/ArduinoUno`

research.

Chapter 2
Related Works

2.1. Smart textiles

Textiles represent an attractive class of substrates for realizing wearable biosensors. Electronic textiles, or smart textiles, describe the convergence of electronics and textiles into textiles which are able to sense, compute, communicate and actuate. As many different electronic systems can be connected to any clothing, a wearable system becomes more versatile, and the user can change its look depending on environmental changes and individual preference.The vision of wearable computing describes future electronic systems as an integral part of our everyday clothing serving as intelligent personal assistants [1].

Smart textiles have a wide range of applications not only in health detection and motion sensing, but in the future they will carry more interactive functions. Soft Speakers [20]and Sonoflex [21] embeds speakers into the fabric.With the development of technology, the battery can also be hidden in the soft fabric [22], which lays the foundation for the multi-functionalization of smart textiles.

And as an interdisciplinary field [23], researchers are also promoting the everyday and fashionable use of smart textiles by developing a variety of tools that help users design on their own [13] [24] [25] [7].

2.2. Design and manufacture of smart textiles

2.2.1 Basic manufacturing process for smart textiles

Based on the existing fabric manufacturing process, smart textiles use smart materials such as conductive materials, deformation materials, color-changing materials, etc. to be embedded into the textile structure through different manufacturing processes to achieve different smart functions. The main manufacturing processes can be summarized as follows: embroidering , sewing, non-woven textile, knitting, weaving , making a spinning , braiding , coating/ laminating , printing and chemical treatments that provide specific features such as controlled hydrophobic behavior [1](Fig.2.1).

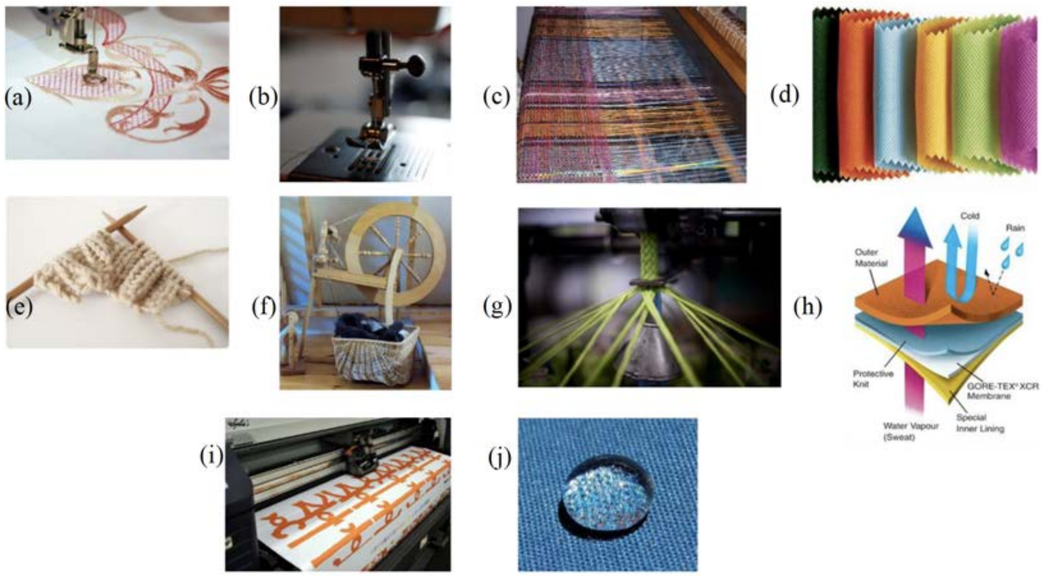


Figure 2.1 Different kinds of textile/fabric manufacturing and treatment. (a) Embroidery; (b) sewing; (c) weaving; (d) non-woven; (e) knitting; (f) spinning; (g) breading; (h) coating/laminating; (i) printing and (j) chemical treatment. [1]

Embroidering

Embroidery crafts in smart textiles often use automatic machine embroidery techniques to create circuits on one or multiple layers of fabric with conductive and non-conductive fibers for various sensing functions, such as real-time interaction with other electronic devices or real-time monitoring of health data.

Embroidered Resistive Pressure Sensor [26] designed and fabricated a fabric-based pressure sensor using resistive sheets and conductive fibers.Tessutivo [10] uses conductive fibers to embroider spiral coils on a four-layer structured fabric, which allows the smart fabric to identify common conductive objects in the home and workplace through contact.

To avoid short circuits and improve the accuracy of sensing, [10] and [26] both require complex designs for the alignment of conductive fibers and the use of multi-layer fabric structures. However, this design method limits its space for appearance design as a smart fabric to a certain extent. The excessive number of layers and complex alignment will also affect the softness and wearing comfort of the material itself.

Scott Gilliland et al. [27] designed a textile interface mapping for conductive embroidery in which six samples are presented: folds, menus, rockers, multi-touch gestures, zippers, and proximity. The study uses these widgets (GUIs) to control mobile electronic devices through the tactile characteristics of the fabric.

Sewing

At the time of hand sewing or prototyping, Punch-Sketching E-textiles [8] introduced us to a production process that uses Punch Needle to achieve simple removal of parts that were missed or unwanted during the manufacturing process. In terms of clothing-based interaction research, the Media Interaction Lab has developed RESi [28] , a sensor interface that can be easily sewn on using the principle that conductive threads fluctuate in resistance with pressure.

Knitting

SensorKnit [29] introduced three types of textile sensors that exploit various textile structures' resistive, piezoresistive, and capacitive properties by machine knitting with conductive yarns. It explores the correlation between the partial knitting structure and the overall electrical properties of textiles. KnitUI [6] provides a new, accessible machine knitting user interface based on resistive pressure sensing. Users can customize the color, size, position, and shape to accommodate their needs.

Weaving

Adapting Double Weaving and Yarn Plying Techniques for Smart Textiles Applications [30] blends smart textiles with traditional spinning techniques to create woven textiles that can change color in response to touch using conductive materials and thermochromic materials. Large-area display textiles integrated with functional systems [31] have produced micron-scale electroluminescent cells by weaving conductive weft threads and light-emitting fibers at the point of contact between the weft and warp threads. It provides a flexible, breathable, and machine-washable flexible display, but it still requires other devices similar to the flexible keyboard to form an integrated textile system.

Braiding

I/O Braid [32] has developed an interactive braided thread with embedded sensing and visual feedback through the spiral repetitive braiding topology of the touch matrix, which senses distance, touch, and twist.

Coating/Laminating

ModiFiber [33] is a silicone-coated, twisted-coil nylon thread actuator that can deform textiles through bi-directional reversible contraction or twisting motions by heat or current.

Printing

Zhou et al.developed an unobtrusive, cheap, large-scale, pressure sensor matrix by conductive ink printing [34] , which can be used for a variety of applications ranging from smart clothing, through smart furniture, to an intelligent table cloth or carpet.

Chemical treatments

Topographie Digitale [12] uses a fabric soaked in conductive ink and pleated to create a stretchable sensor.There are also studies on embedding alkaline batteries into conductive textiles using chemical treatments/.

2.2.2 3D printing technology on smart textiles

3D printing, an emerging manufacturing process, is also increasingly being used in the manufacture of smart textiles. FabriClick [11] prints the structure of the button on the fabric, and ClothTiles [35] uses 3D printing and shape memory alloys to enable the fabric surface to be deformed in a controlled manner.

I think this is a very good attempt to break the structure of ordinary garments and use 3D printing technology to extend the surface structure of the fabric into a three-dimensional sphere with clear physical signs and tactile feedback. I think this will be a big trend in the future of clothing, which does not stay in the pre-existing garment structure but evolves with the technology. But in addition to haptic feedback, I think it can also achieve more functions, such as sensing body movements or changes in the surrounding environment.

2.2.3 Other craft combinations experimentation

In addition to these basic crafts, through some unconventional special fabric manufacturing processes such as bead embroidery, sequin embroidery, kinetic modules, etc., we can find more possibilities for future smart textiles and garments. As early as 2009, Buechley et al.has been building the relationship between fashion elements and technology by looking at the diversity of e-textile process technologies [36]. Clint Zeagler et al. created a multi-use pointing wheel using multiple layers of embroidered, PVDF film sound sequins and a tilt sensor using hanging beads, embroidery and capacitive sensing [37] . This study has shown us the possibility of using a variety of widely used apparel assets such as sequins, beads, and embroidery in the manufacturing process of smart textiles. However, it is mainly by comparing the commonality of existing sensors and these garment assets to reproduce the functions of sensors in smart textiles, and not much attempt has been made to the overall aesthetic design of the textiles and the design of the combination of existing techniques. Nojima Laboratory [38] has developed a toolkit for creating kinetic garments based on smart hair technology that can be fitted with kinetic features for textiles. This extends the three-dimensional expression of the textiles. PneuSleeve [39] is a compact and expressive fabric-based forearm sleeve that can provide a wide range of tactile stimuli such as compression, skin stretching, and vibration developed by a research team at Facebook Reality Lab.

2.3. Application of conductive materials in smart textiles

By combining the above manufacturing processes we can find that the design and manufacture of smart textiles are almost always inseparable from conductive materials. In order to make smart textiles a part of the Internet of Things, the entire electronic circuit is connected and electronic signals are transmitted by developing various conductive materials that can be adapted to flexible interfaces.

Tessutivo/ and SensorKnit/, among others, use conductive fibers, the printing of Fabric PCBs requires conductive inks, and Topographie Digitale/ uses conductive dyes. Conductive ink [3], conductive rubber [4] and conductive tape [5]. All of these materials can be combined with cloth to detect the user's movements because they are flexible conductive materials that can be stretched; however, they can easily be peeled off or confined to a flat shape.

Chapter 3
Design Progress

3.1. Concept design

Through related research, I learned about the basic design and manufacturing methods of extant smart textiles. While learning, I also realized the limitations of smart textiles based on ordinary textiles.

The structure of ordinary textiles is too fixed, and basically, the design space is limited to a two-dimensional plane. Apart from features such as stretch and elasticity, the surface structure of textiles can only be changed by pleating or stitching. The design space is quite limited, and it is difficult to realize integrated design and production if multiple sensing functions are to be combined into the same textile for an already fixed and independent design and production method.

There are several important problems with the current smart textile research, as follows.

- One technical design corresponds to one sensing method, it is fixed and the design space is very small.
- The design space is limited to a two-dimensional plane, and the surface structure is too fixed to accommodate various sensing functions.
- It is difficult to combine multiple sensing functions into the same textile without affecting the overall comfort and aesthetics.

In view of the above problems, I think the ideal intelligent textile in the future should have the following conditions.

- Large design space to realize sensing and other functions while freely designing its appearance and texture. There is still a lot of design space in the appearance while realizing the intelligent functions you want.

- The design can be modularized to achieve different smart functions by adjusting the material, shape and size of each small unit.

Among the available textiles, I think sequin embroidery textile is by far the most suitable choice for.

- Sequin textile is very common in daily life as a decorative textile. And it is not only limited to daily life, but also has very wide application in stage performance and decoration.
- It is very eye-catching and can appear as the main decoration of the garment. If this powerful decoration is linked with the function, it is easier to attract people's attention and make the intelligent function show in a more obvious and diverse form, so as to stimulate the wearer's desire to wear and design, and then promote the daily use of intelligent textiles.
- Sequins of sequin textile are very diverse, it has variable material, color, size and shape, and various embroidery methods, even with the playability and interactivity of flipping sequin embroidery. Sequins float on the surface of garments, giving them a more three-dimensional form and a vertical design space different from that of ordinary textiles.
- Sequin textiles are made up of individual sequins, and we can design more different intelligent and interactive functions by combining different materials, shapes, sizes, colors, etc.
- Sequin textile has a different tactile sensation from ordinary textiles, and there is a lot of room for innovation in the tactile interaction of clothing materials.

This study will focus on the experiments and discussions on the relationship between the functional and decorative aspects of 3d printed conductive sequin embroidery on smart textiles.

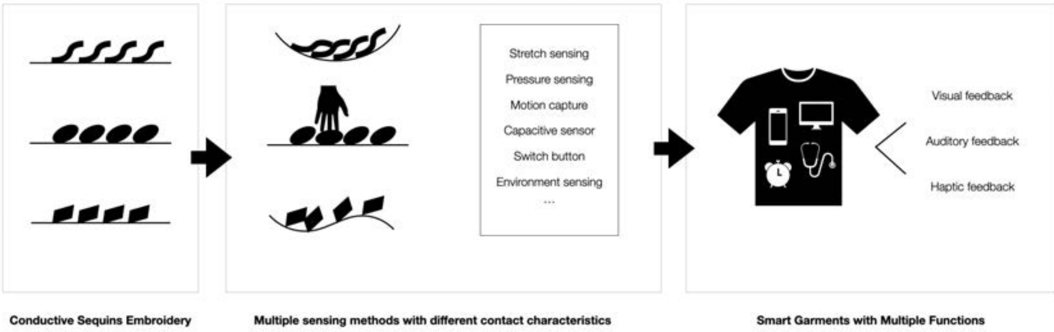


Figure 3.1 System image

3.2. Prototype I. Basic circuit testing

In Prototype I, I will confirm the feasibility of conductive sequin embroidery as a smart textile by replacing conductive wires with conductive sequins 3D printed from conductive PLA to make capacitive sensors and to control the brightness of LEDs by zones.

3.2.1 Capacitive sensor

In this part, I focused on the interaction of input and made a prototype of conductive sequin embroidery. I used a 3D printer (Adventurer3 by Flashforge) to create sequins with a diameter of 10 mm and a thickness of 0.5 mm using conductive filament (Conductive-PLA by Proto-pasta). The resistance of one sequin was 750 Ω.

By using ordinary sewing thread, I made 3 horizontal rows of 7 sequins, and the resistance per row (4cm long) was 125kΩ. The third sequin was connected to the Arduino UNO based on the circuit shown in Figure3.3, and touched as a capacitive sensor. The LED lit up when I touched any sequin that was in contact with the sequin between the alligator clips. When I changed the direction of the sequins, it was naturally divided into energized and unenergized areas (Figure

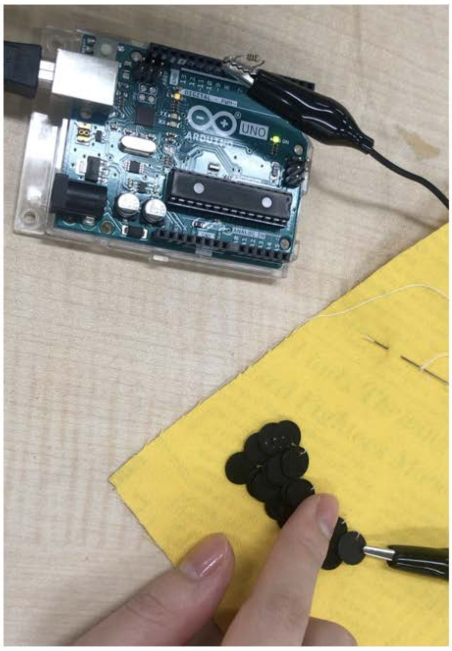


Figure 3.2 Conductive Sequins(Left) and Capacitive Sensor(Right)

3.2).

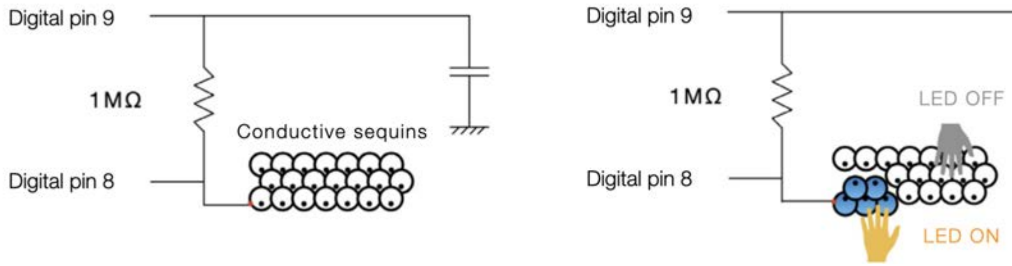


Figure 3.3 Capacitive sensing circuit

By touching the embroidered area, we can see the LEDs blinking on the Arduino board, and I proved that it is feasible to form a circuit through conductive sequins instead of wires. However, since the sequins made by the 3D printer are thick and hard, the contact area between the sequins is somewhat narrow and the circuit connection is sometimes not very stable.

3.2.2 LED Blinking circuit

I have developed a prototype of an LED control circuit using conductive sequins as an electronic circuit. I prepared a piece each of conductive thread (resistance: 28Ω/ft) and tri-color (red, yellow, and blue) LEDs (LilyPad LEDs), and created three switch functions with the conductive thread as shown in Fig. 3.4. Each LED is connected to a microcomputer (ESP32 VMW101) for input.

By changing the orientation of the conductive sequins as shown in Figure 3.5, the connection between Figure 3.5A and R, Y, B changed and the LED lights emitted separately. However, as mentioned earlier, the LED light was weak due to the high resistance of the conductive resin, so touch interaction was more suitable. In addition, the contact of the sequins was unstable, and in some cases, the sequins did not emit light until a large force was applied.

3.2.3 Summarization and discussion

By using 3D printed conductive sequins to make capacitive sensors and circuits to control LEDs, I confirmed the possibility of conductive sequins embroidery as a smart textile process.

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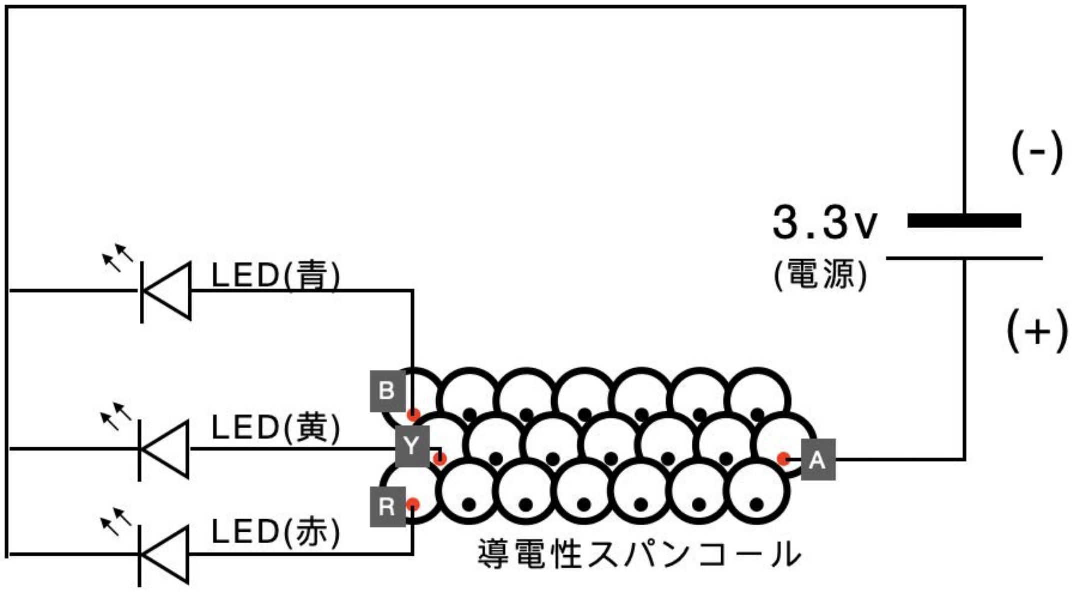

Figure 3.4 circuit diagram: LED flashing circuit

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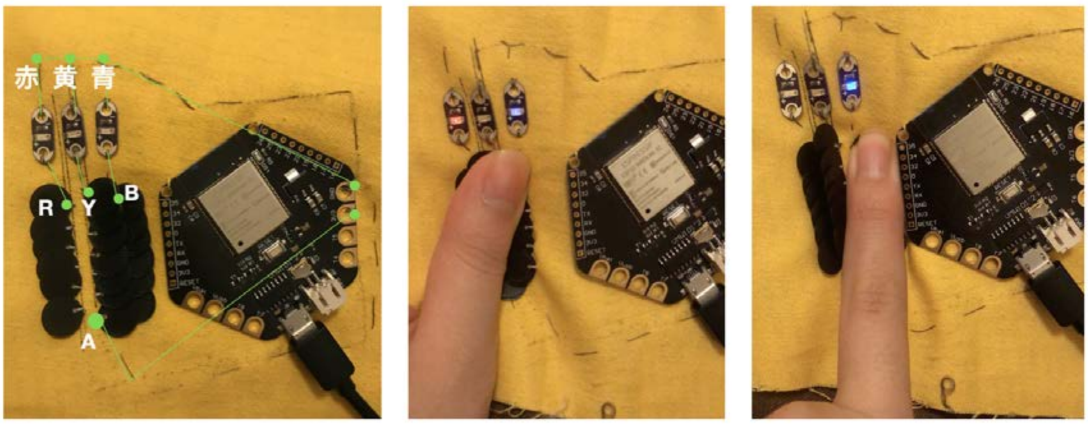

Figure 3.5 Left: LED connection,Middle and Right: LED flashing result

In Prototype I, I used the shape and size of the most common sequins, referencing the most basic single sequin embroidery method. This flat circular sequin will be unstable when in contact because of its stiff material and also its light weight. And because of the high resistance value of the conductive PLA used, it will affect the luminous effect of the LED in the series circuit.

Therefore, in Prototype II, I made improvements to the shape and embroidery of the sequins, as well as the circuit design.

3.3. Prototype II. Sensing sleeves

3.3.1 Wavy sequin embroidery

In response to the previous problem of poor circuit contact, I redesigned the shape of the sequins by increasing the curvature of the sequins to produce a partial locking effect when two sequins are stacked on top of each other. This controlled the movement path of the sequins to some extent. Moreover, I changed the shape of the sequins from round to tile to increase the contact area between the sequins, thus making the contact between the sequins more stable (Figure3.6).

To further stabilize the sequin contact, I replaced the normal cotton thread with a rubber thread to ensure that the sequins are all connected in their natural state.

I chose the sleeve as the embroidery area for the sequins, and when the sleeve is bent a gap will be created between each row of sequins, thus leaving the circuit in the OFF state. However, due to the use of rubber thread, we must make the backing textile on the stiff side, otherwise unnecessary folds will be created, which will affect the effect of the control.

I divided the sequin embroidery into three areas, as shown in the figure (3.7) the top piece of each area is connected to the Analog Pin (blue mark) and the bottom piece is connected to GND (yellow mark). Each area is followed by an LED strip sewn on the inside of the sleeve. The LED strip sewn on the inside of the sleeve is controlled by toggling the sequins in each area. When the sequins of each area are toggled and the circuit is in the OFF state, the LED strip glows. The brightness and extinction of the LEDs are used as control feedback for conductive sequin

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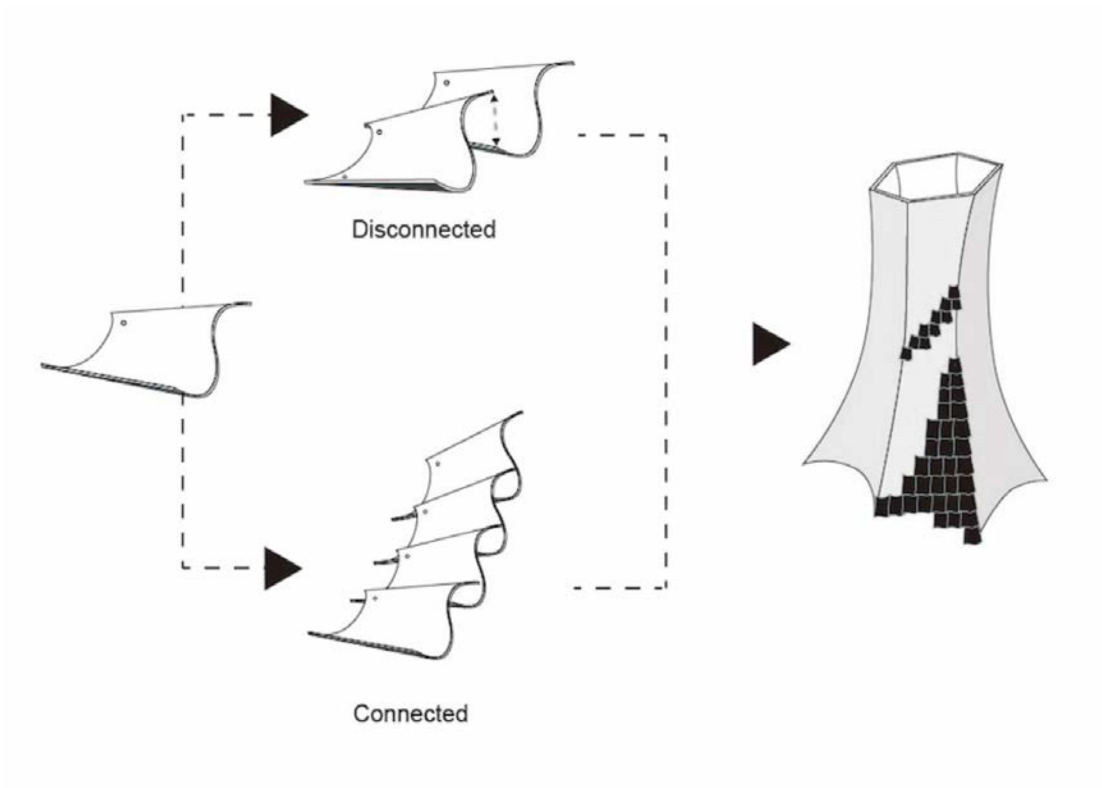

Figure 3.6 Sequins are toggled to change contact conditions

embroidery.

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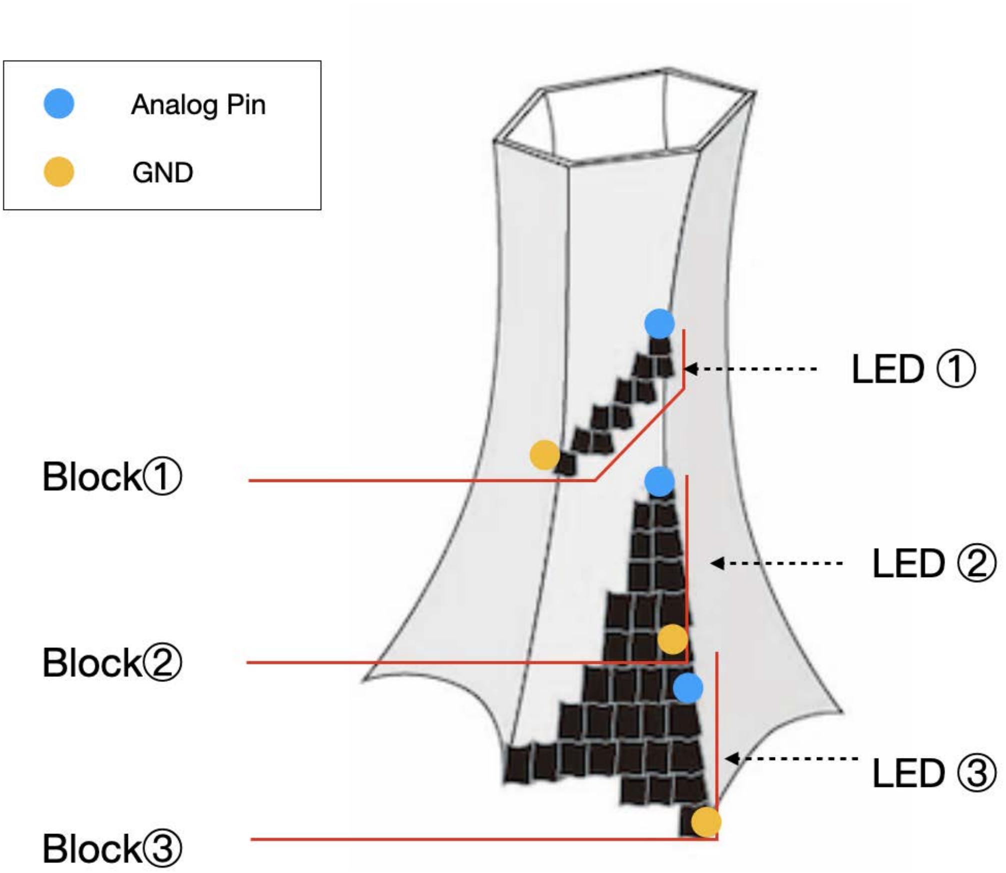

Figure 3.7 3 blocks of conductive sequin embroidery and the condition of circuit connection

3.3.2 Installation

Three sizes of conductive sequins were made using 3D printing: 10 mm long and 6 mm wide; 15 mm long and 9 mm wide; and 20 mm long and 12 mm wide; all with a thickness of 1 mm. During testing, it was found that it was difficult to print the bends more accurately when the thickness was below 1 mm (Figure3.8).

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Figure 3.8 Making the new version of sequins by 3D printing

I simulated a slightly rigid sleeve model by actually embroidering sequins on organza and mounted it on the garment (Fig.3.9) The Arduino Uno was used to receive the electrical signals generated by the conductive sequin embroidered areas and to control the brightness of the LEDs.

3.3.3 The evalution of sensing function: Bending sensor

With Prototype II, I implemented the touch sensing function and bending sensing function by means of a wavy three-dimensional structure and elastic rubber sewing thread.

Compared to Prototype I.

- The wavy three-dimensional structure provides more stable circuit connectivity.
- In addition to the switch function and capacitive sensing, we get a stretch sensor and a bending sensor, which allow us to sense the bending of body parts such as arms by means of wavy sequins.
- By embroidering the sequins of different sizes in the order of their size, we got a more fluid and smooth external structure.
- By trying to use rubber sewing thread, we increased the controllability of circuit opening and closing.

3.3.4 Review and summarization

In March 2021, prototype II was demonstrated and presented in DEMO at the INTERACTION 2021 conference of the Information Processing Society of Japan. Although the presentation was conducted in an On-line format due to COVID-19, many comments and suggestions were received as well.

First of all, the design of conductive sequin embroidery received positive comments and people expressed interest in this new smart textile.

- The overall design is very new and interesting, with a futuristic look.

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Figure 3.9 Real installation effect

- We are looking forward to the application of conductive sequins in places other than the sleeves.
- The shape of the sequins is similar to fish scales and armor, giving people a sense of protection.
- Curious about the feel of the conductive sequin embroidery textile

At the same time, people also gave some questions and comments.

- With the increase of sensing points, the wiring of the whole circuit will become more and more complicated, so we need to make use of the shape and structure of the conductive sequins to simplify the circuit as much as possible.
- Looking forward to sensing methods other than touch. For example, moving with body movements to monitor the body's movement status.
- The current functional area division is not obvious, and the sensing area can be divided by using non-conductive materials.
- Data output methods other than LED feedback can be considered.

3.4. Workshop I: Trial of conductive sequin embroidery module in smart garment design

3.4.1 Process of the workshop

- Time: Friday, April 23, 2021, 11:10 - 14:30
- Place: SS302, Kyouseikan, Hiyoshi Campus, Keio University
- Observation target (main): Future Crafts Member Conductive Sequin Module Group (Group B, 3 students)
- Experimental purpose: To verify the usability of conductive sequin embroidery textile as a material for garment design.

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Figure 3.10 Design Process

- Experimental means: Let the experimental subjects use our pre-prepared conductive sequin embroidery module to design a garment with smart functions and interview their feelings about using it (Fig.3.10).

- Experimental process:

  I prepared three types of 6 modules: flower, triangle, and tile (Figure3.11). The flower type can realize the ON/OFF change of the circuit by touching the flower heart and petals. The triangle can be arranged in an orderly manner with the body's movement to generate electrical signals. And the tile type can detect the degree of bending of the textile.

  The three people in the group selected triangle and tile type conductive sequin embroidery modules. They designed a garment with a cat theme that can help people correct their sitting posture. They were interested in the three-dimensional structure of the tile-type sequin embroidery, which resembled the curvature of a cat's body with its back arched, and was smooth to the touch. They also associated the triangular module with the flesh pad

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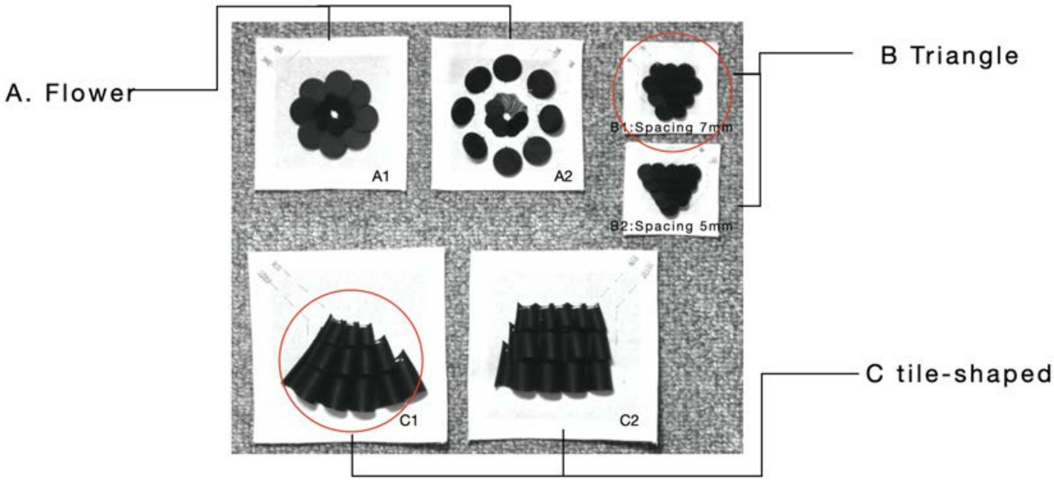

Figure 3.11 Three types of 6 modules: flower, triangle, and tile.

on the cat's paw, and chose the triangular module as the decoration. When the user's back is bent, the "cat's" back is also bent, and the sequins break contact with each other, thus lighting up the LED on the chest to remind the user of the correct sitting posture (Figure3.12).

3.4.2 Interview and summarization

Through our interviews with the participants, their evaluation of the modules can be divided into the following three parts

Stylized appearance

The unique three-dimensional structure and touch of the conductive sequin embroidery will stimulate the imagination of the garment designer, and its distinct difference from ordinary textile will give participants a sense of magic. And its unique appearance will give the wearer a sense of confidence that he or she is the protagonist.

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Figure 3.12 Designing and Making

Interaction mode

Participants had many ideas about the application scenarios and interaction methods of the conductive sequin embroidery module, for example, it can sense the change of environment through the movement of the sequin or to sense the movement state of the body. And by adding smart sensing function to the garment, it can add a lot of convenience to life, and also show their personality through the unique design of conductive sequins. It is also possible to realize the interaction without visual operation through the touch of different modules.

Challenges

The problems of washing the conductive sequin embroidery textile, as well as the problems of power supply and electricity safety, and the problem of longer sewing time still need to be solved.

3.5. Summarizaion

By combining what I learned in Prototype I and II and Workshop I, we can open up the idea of designing conductive sequin embroidery textile and make it more diversified and adaptable to more application scenarios. Different sequins can be adapted to different applications. For example, flat sequins are more likely to sense the movement of the covered body, and curved sequins are more likely to sense the bending of the covered body. Moreover, different embroidery methods and different materials of sewing threads can also affect the way of contact and stability. Therefore, based on our experience, we can summarize the system structure of conductive sequin embroidery textile and the properties of sequin such as conductivity, shape and softness, texture, bistability, and locking structure as follows.

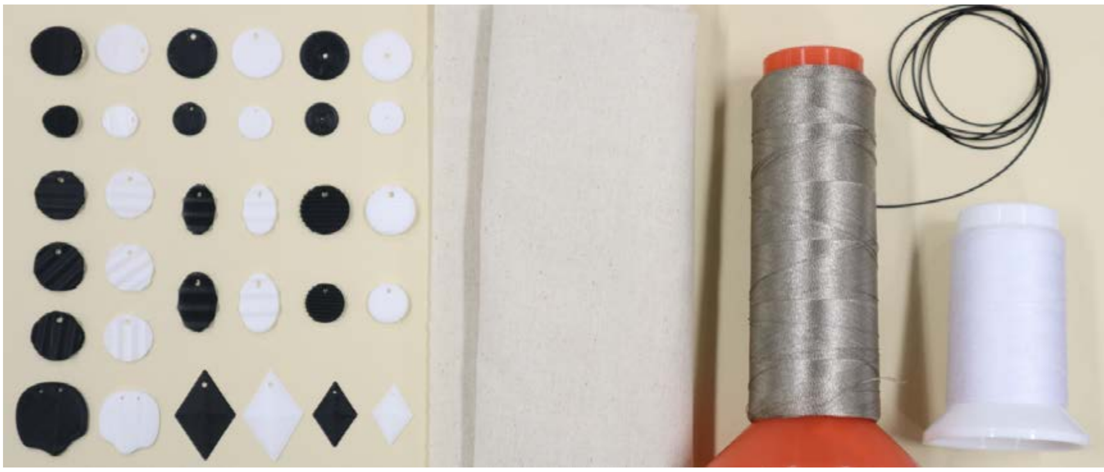

Figure 3.13 Conductive sequins (black) and Non-conductive sequins (white), Linen,sewing threads (conductive sewing threads,Cotton thread and Rubber thread).

3.5.1 System structure of conductive sequins embroidery textile

This system consists of conductive sequins, textile, and thread (Figure 3.13), where multiple conductive sequins are sewn to the textile using thread. As shown in Figure 3.14, when the sequins are laid down, they make contact with the sequins beside them, resulting in a closed circuit. However, when the sequins are touched, and a gap is created between the sequins, the circuit is opened.

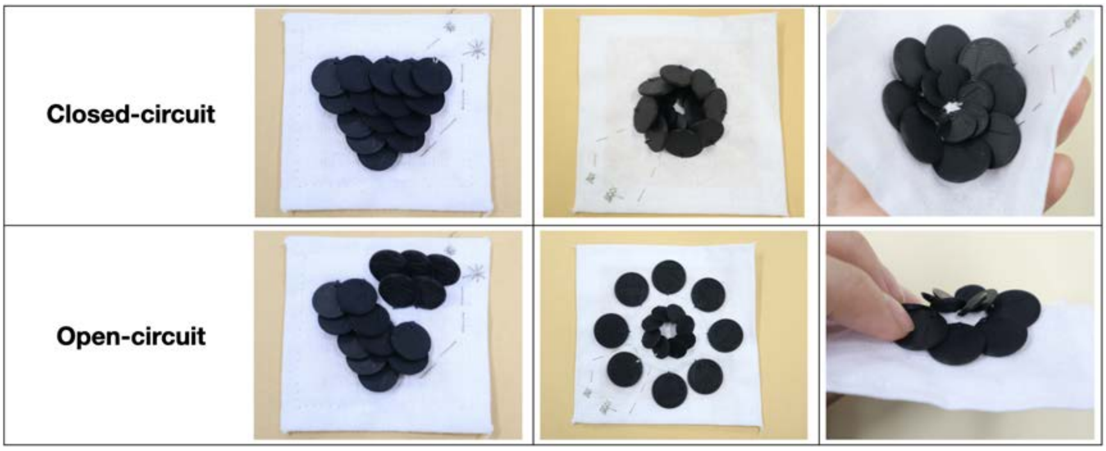

Figure 3.14 Open-circuit and Closed-circuit by flipping the conductive sequins

The conductive threads extending from the conductive sequins at both ends are connected to a microcomputer(Arduino Uno), which detects when the circuit is closed. The connection state of the conductive sequins also changes depending on the direction, angle, and strength of bending the textile(Figure 3.15).

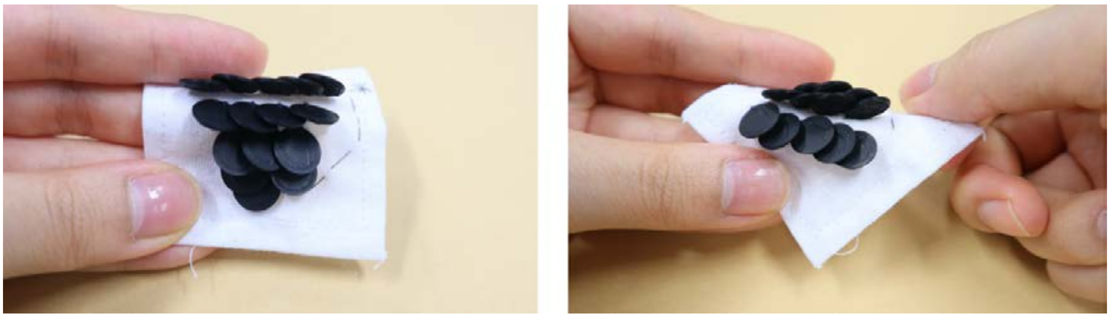

Figure 3.15 Connection of the circuit changes with the bending direction, angle and strength of the textile

3.5.2 Properties of conductive sequins embroidery

Conductivity checking

In this study, I used Composite Conductive PLA[1] as the conductive filament. The material of this filament is PLA-based, and its volume resistivity of 3D-printed parts perpendicular to layers is 30 Ω -cm.

To separate the electrically contacted parts from the non-connected parts, we used a non-conductive PLA material[2]. As shown in Figure 3.16, there is no electricity between adjacent sequins because of the non-conductive material in between. This makes it possible to create complex circuits. Also, since I used a 3D printer to create the sequins, I can easily customize them to other shapes such as squares and scales.

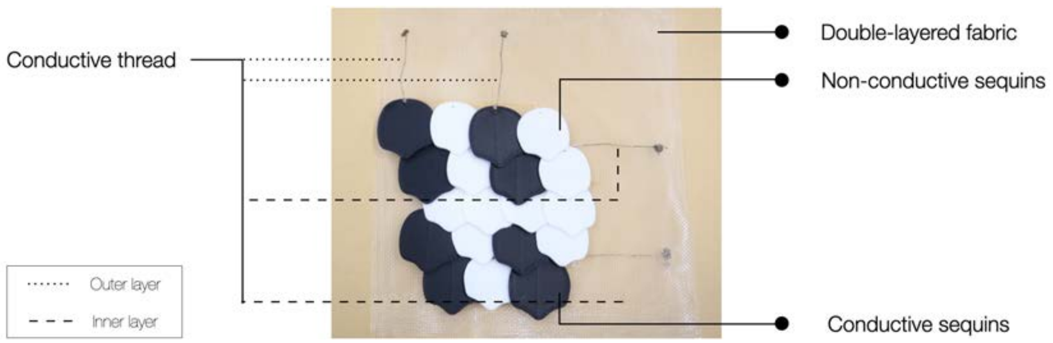

Figure 3.16 Modules consisting of conductive and non-conductive sequins

Shape and softness

By changing the size and shape of the sequins, the softness of the textile can be changed. If the sequins are flat, the textile will bend flexibly. However, if the surface of the sequin is curved, it will overlap with the neighboring sequins when the textile is bent, making the textile hard to bend. I printed out the curved sequins and sewed them onto the textile; as illustrated in Figure 3.17, the curved

1 `https://www.proto-pasta.com/pages/conductive-pla`

2 `https://www.flashforgeshop.com/product/10066`

sequins are more difficult to bend: the higher the angle of the curve, the stiffer the textile tends to be.

Figure 3.17 textiles embroidered with curved sequins have much less lateral curvature than those embroidered with flat sequins.

Texture

One of the features of 3D printing is printing textures on the surface of the sequins to change how they feel. I printed several samples as shown in Figure 3.18. By changing the waves in the vertical and horizontal directions, we can change the tactile feel, which is also applicable to spike shapes and smooth textures. By changing the size of the surface convexity, we can also control the conductivity and the electrical resistance.

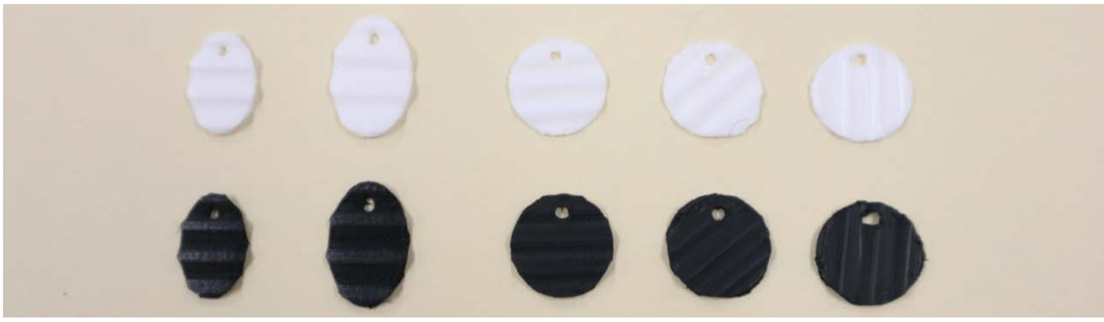

Figure 3.18 The direction of the final texture will change depending on the location of the punched holes.

Bistability

The holes in the sequins described above are located close to the edge, and because of that, they will return to their original positions after being turned over. This

Figure 3.19 After flipping each line of sequins there will be a gap in the middle, which allows the circuit on both sides of the gap to be broken.

allows the circuit to open only when the user touches it and turns it. However, the circuit can be kept in the flipped state by placing the holes in the center. As shown in Figure 3.19, when the sequin is turned over, it does not return to its original position and needs to be manually turned back again. In this way, we can create a circuit like a slide switch.

Locking structure

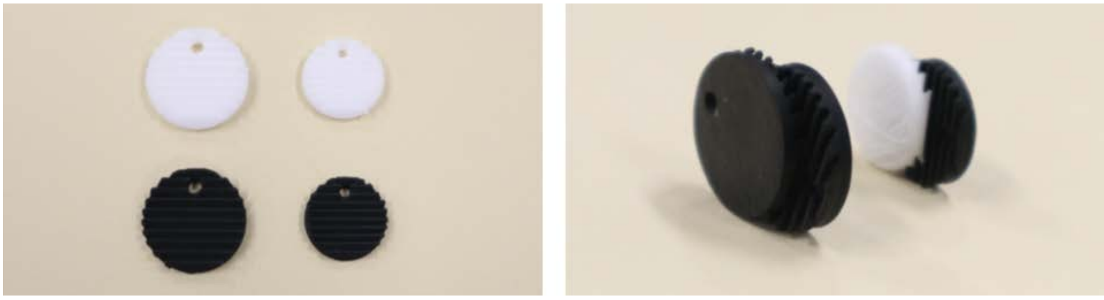

Figure 3.20 Locking structure

The texture can also be used to keep the sequins attached, giving them a locking effect, as Figure 3.20 illustrated, making the unevenness slightly angled and stair-stepped and making the tips pointed. When sewing the sequins onto the textile, the angle of the texture should be different from each other, so that when the sequins are pressed together, they will bind together and not separate. In this case, I set the height of the grooves at 1mm and the distance between them at 1mm. This can be peeled off by applying force. This makes it possible to create a circuit similar to the slide switch described above and control the textile's softness.

The sequin circuit described above is a switch circuit that detects when two sequins are in contact with each other. Changes in electrical resistance are detected. On the other hand, since the material is conductive, it is possible to design a circuit that detects changes in capacitance. In this case, a resistance of 1MΩ to 10MΩ can be used, and the circuit can respond when the sequin is touched or approached(Figure 3.3).

3.5.3 Design space

Through the above analysis and summary of 3D printed conductive sequin embroidery, I have summarized the design space as follows.

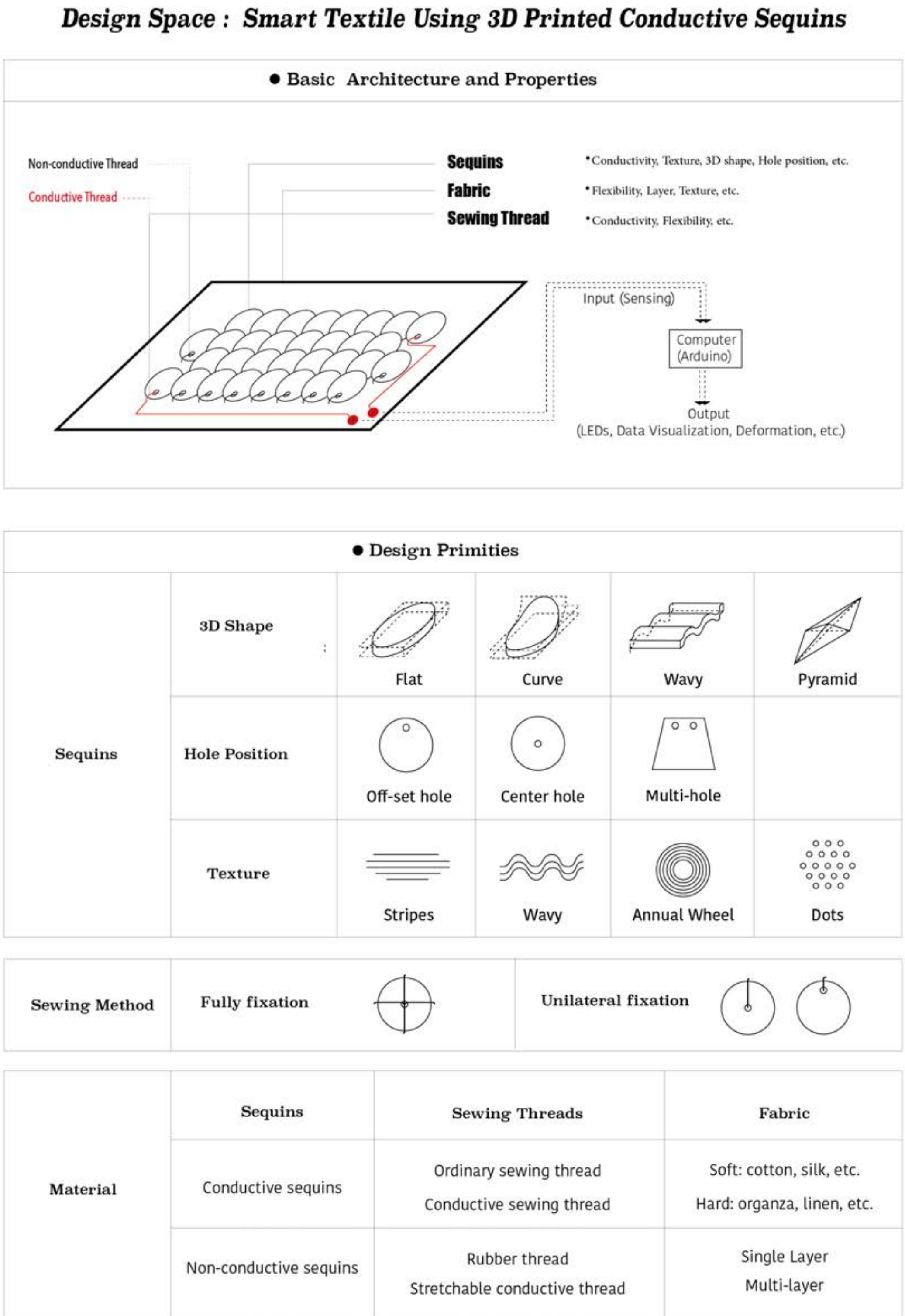

Figure 3.21 Design Space page1

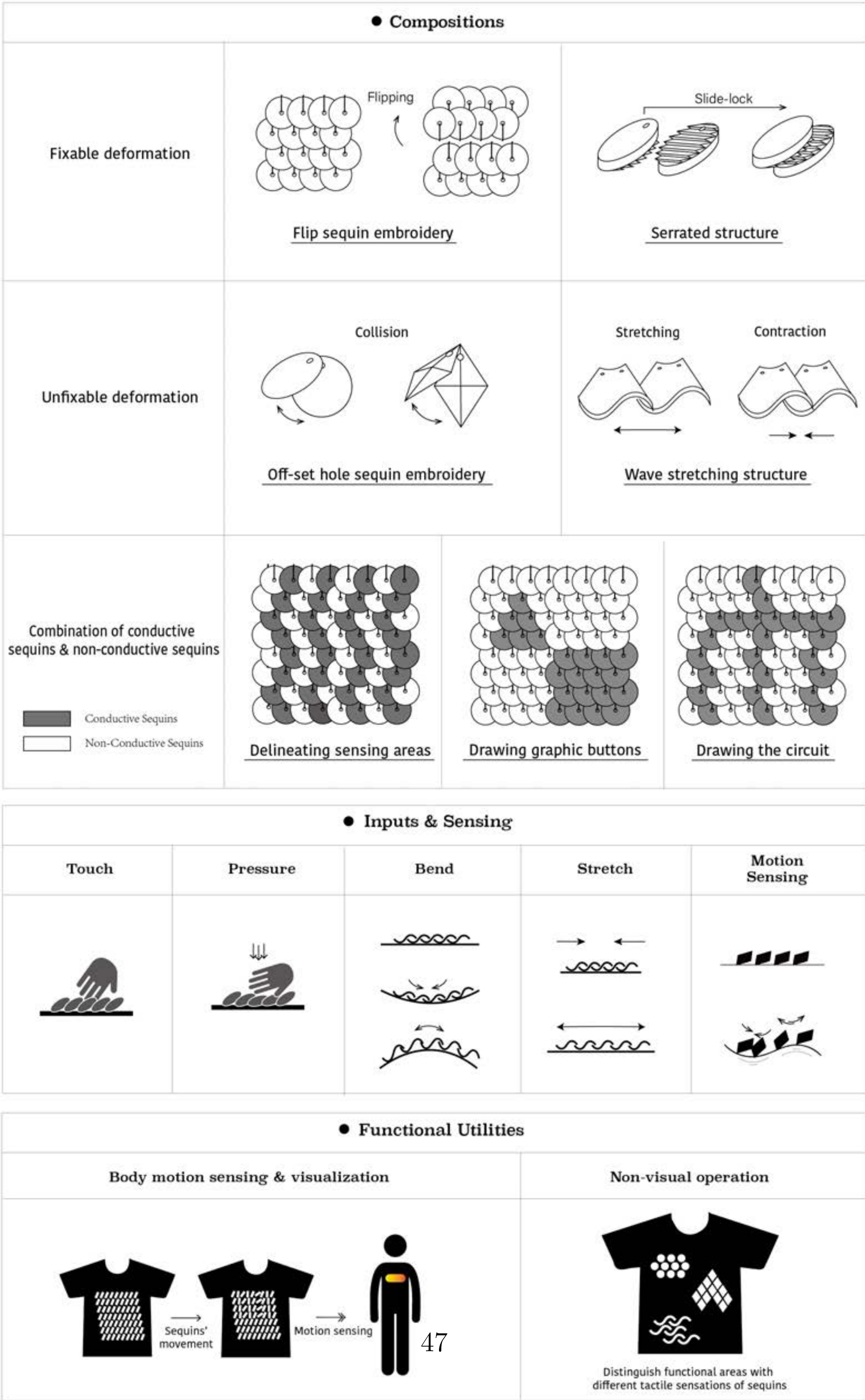

Figure 3.22 Design Space page2

Chapter 4
Application

4.1. A garment that visualizes the body's movements

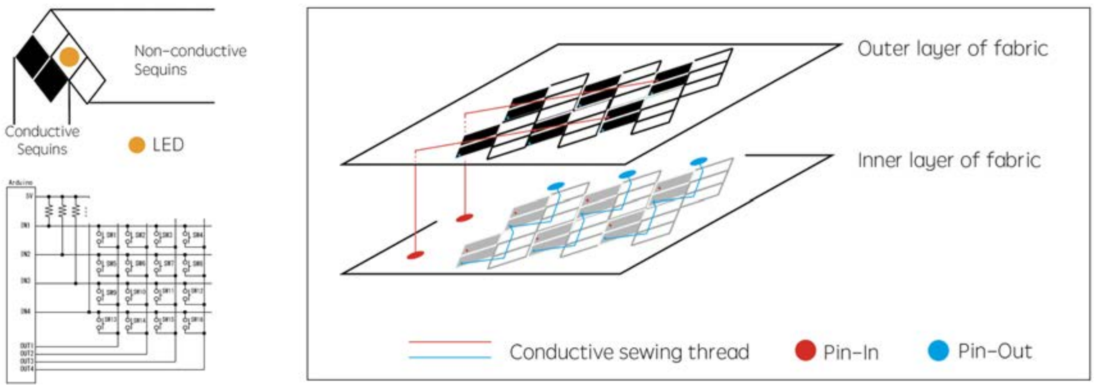

Figure 4.1 A total of 84 modules were used for this garment. The garment consists of two layers to prevent short circuit, the outer layer is organza and the inner layer is cotton textile.

First, I developed a garment that visualizes human motion. For human motion sensing, we need a conductive sequin embroidery textile that is more sensitive to motion sensing and has some stability. According to the research results above, I prefer a sequin with a flat structure, but in order to ensure the stability of the contact, I should increase the contact area between the sequins. So I chose a flat quadrilateral cone structure inspired by fish scales this time, which is flexible enough to collide up and down with the body's dance, and the contact area between its sequins through the diamond matrix arrangement reaches one-fourth of the whole sequins area, which greatly enhances the stability of contact. In addition, in order to improve the accuracy of sensing, we need more than one module to work as a sensor at the same time. This requires that the sensing units of each are independent from each other. For this reason, I use non-conductive sequins of the same shape but different colors as separators between sensing units, which both functionally divide the sensing units and give visual cues to the user as the texture of the textile. I still chose LEDs as the feedback representation of the sensing, but in addition, I used TouchDesigner/footnotelabelTouchDesigner to graphically represent the data changes of each sensor in order to more intuitively observe the data changes of human motion sensing, as shown in the figure: reffig: garmentvisualization.

4.1.1 System structure

The circuit of a module becomes closed when two conductive sequins are in contact, as shown in the figure: reffig:circuit2. When two conductive sequins are in contact with each other, the circuit of one module becomes closed and 6 x 14 switches are arranged. led tape (NeoPixelsfootnotelabelNeoPixels) `https://cdn-shop.adafruit.com/datasheets/WS2812.pdf`) is placed on the reverse side of the textile, and when the conductive sequins come into contact as switches, the LEDs start flashing. This allows the user's body movements to be visualized (Figure: reffig:circuit2 shown).

4.1.2 User interview

I invited a dancer to put on a dress made of conductive sequin textile and let her move freely, as shown in the figure reffig:dancer. I interviewed the dancer, who was highly attracted by the tactile feel of the dress and the sound of the sequins colliding:

- "I think the feeling of touching the scales is amazing, it is smooth to touch and when the place you touch responded with light, it is just like talking to your body."
- "I really like the sound of the scales colliding, and when I wear it I want to swing my body, I think it's cool."

- "If this interface can be more lightweight, I would love to wear it to do sports or go to a travel."
- "I'm looking forward to wearing it with my friends and give them hugs."

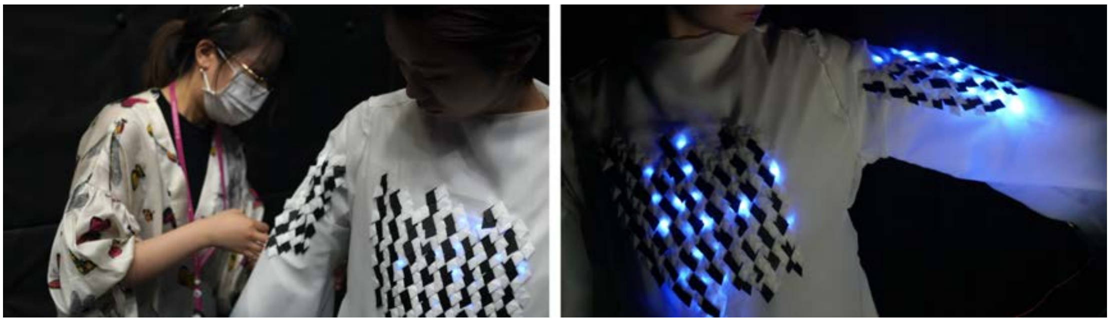

Figure 4.2 Let the dancer to wear the garment made of conductive sequins textile.

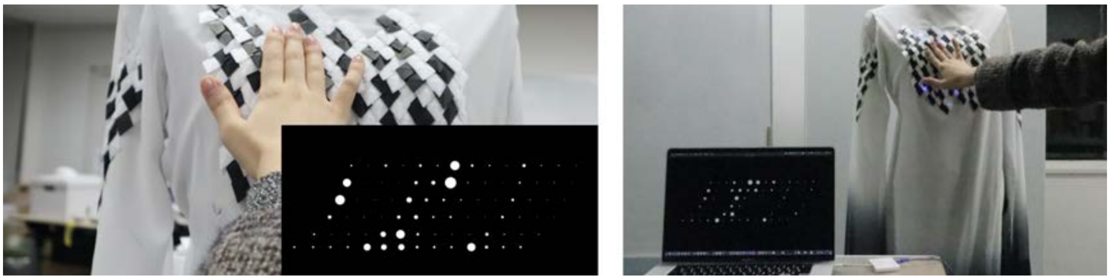

Figure 4.3 visualization of the garment: When the two conductive sequins in each module come into contact, the small white circles at the corresponding locations will change size. The tighter the contact, the larger the circle becomes.

Through our interview, I can clearly see that the conductive sequins bring users a new experience in terms of touch and surface characteristics. The conductive sequin embroidered textile gives the user triple action feedback such as visual, auditory and tactile sensations. In addition to the visual feedback brought by the LED and the auditory feedback generated when the sequins collide, the collision of the sequins themselves will also serve as a kind of tactile feedback only to the user, allowing the user to focus more on their own body movement, just like "Talking to your body".

In addition to real-time feedback on body movements, you can also interact with others through touch, or send your own body signals through the suit. I think this represents the possibility of exploring the use of conductive sequin embroidered textiles on clothing for human social behavior as well.

But in addition to the above advantages, we cannot ignore the weight of the textile and the stability of the wiring, which is the part I have to improve afterwards.

4.2. Visualization of ankle movement

I also made a prototype of a sample that displays body movements on a screen. This consisted of a curved, 25 mm long conductive sequin textile embroidered with rubber thread attached to the ankle. Since the embroidery thread is elastic, it fits perfectly to the movement of the textile and can take the movement of the ankle more accurately. Then I converted the movement of the foot into the particles' movement on the screen. I can change the sequins' shape, size, and arrangement to match different functions and different body parts.

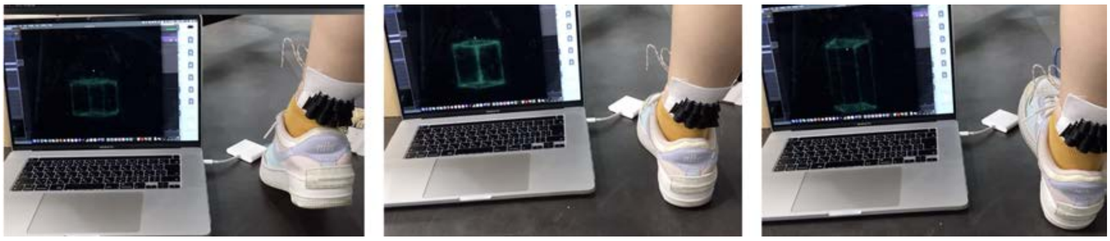

Figure 4.4 visualization of ankle movement: The cube will become shorter when the foot is padded and will elongate when the heel is placed on the ground.

Chapter 5
Evaluation and Discussion

5.1. Workshop II. Trial and evaluation on design space

5.1.1 Process of the workshop

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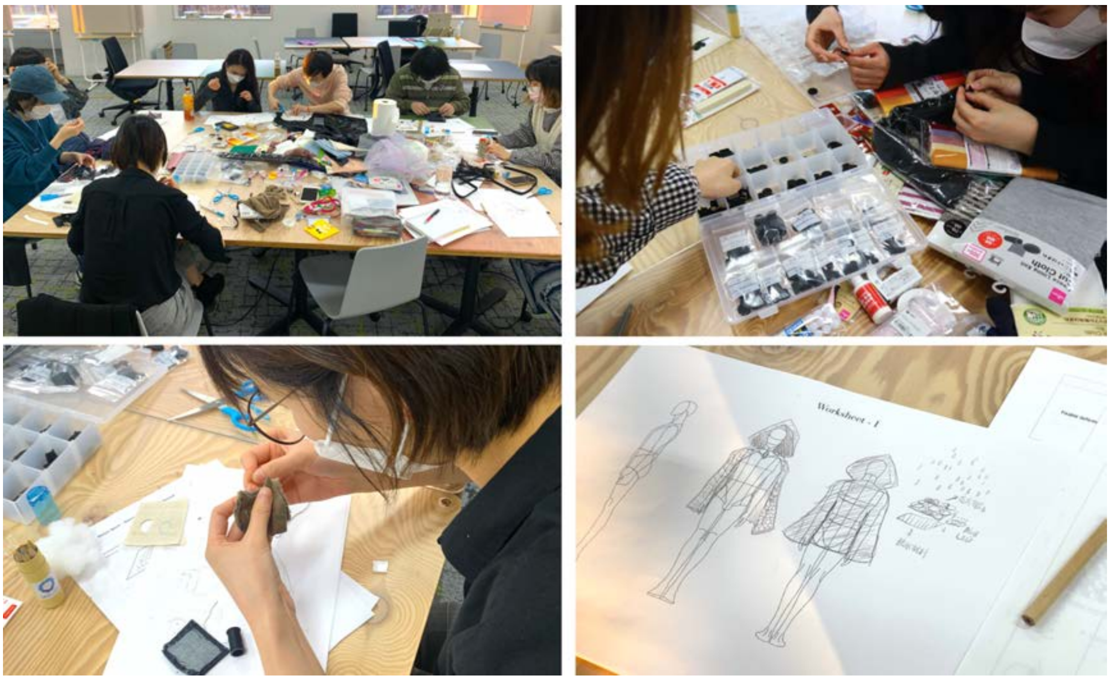

Figure 5.1 Workshop II

- Time: January 22nd, 2022 14:30 - 18:00

- Place: SS302, Kyouseikan, Hiyoshi Campus, Keio University
- Observation target: 8 KMD students
- Experimental purpose: By explaining the design space of conductive sequin embroidery textiles to the participants and allowing them to freely design smart garments and make prototypes using a variety of 3D printed conductive and non-conductive sequins, I can observe and verify that.

  a. Degree of understanding of design space

  b. Application of this design space in design practice

  c. Participants' enthusiasm for designing conductive sequin embroidered smart textiles

  d. The utility of this design space for the customization of conductive sequin embroidered smart textiles
- Detailed settings:

  a. There are no additional restrictions on the participants' designs other than introducing the design space to them.

  b. During the two hours, designers were free to use their imagination as much as possible, and were free to create their own designs after briefly understanding the design principles and elements in the design space.

  c. No fixed toolkit was set, and as many sewing tools and textiles as possible that might be used in daily life were provided. The materials were also picked freely.

  d. The seating arrangement of the participants was in the form of round tables to facilitate communication and to create a relaxed and casual atmosphere for experimentation. (Fig.5.1).
- Agenda:

  14:30-14:55 Experiment introduction: conductive sequin embroidery smart textile and its design space

  14:55-15:15 Introduction of materials and samples, and basic embroidery methods

15:15-15:45 Design and material selection

15:45-17:45 Making (including 15 minutes of break time)

17:45-18:00 Presentation and interview

5.1.2 Design and making process

- More attention to the connection between sequins: generally more interested in sequins with complex structures (complex textures, lockable structures, openwork structures, etc.).
- Participants were very interested in a variety of different materials and textiles.
- The sewing process was too tedious and most of the participants spontaneously used more labor-saving methods such as textile double-sided tape to complete their work.
- Participants were very curious about the many types of sequins and were spontaneously trying to arrange and combine sequins of the same type or different types.
- Two participants requested to make another hole in the existing sequins during the production process.
- One participant asked a circuit design-related question during the design process. More participants chose to ask me questions related to the circuit configuration during the textileation process. The design purpose proposed by these participants was clear, and after answering Half of the participants came up with the idea of laminating two materials on one sequin, e.g., one side conductive and one side non-conductive.
- (Not excluding the bootstrap effect of the sample example) The general idea was to use LEDs to provide feedback on the interaction between the conductive sequins.
- Three participants had design drawings that included elements of circuit design. That is, the overall design was started at the initial stage of design

in conjunction with the circuit configuration. The rest of the participants used the design of the exterior first and expressed to me the need for the smart functions they wanted to achieve during the production, and asked questions about how to configure the circuit based on the current exterior design

5.1.3 Showcase of prototypes

- Participant A:

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Figure 5.2 Participant A

A would like to design a "back wing" that can sense the wind. The wind will blow the sequins to control the LEDs, and the conductive sequins will be glued with feathers to make the garment more sensitive to the wind(Fig.5.2).

Materials:

Sequins: round partial hole conductive sequins (diameter 15mm, thickness 0.5mm)

textile: silver reflective textile, white organza lace

Sewing thread: conductive sewing thread, transparent non-conductive sewing thread

Others: feather, LED

- Participant B:

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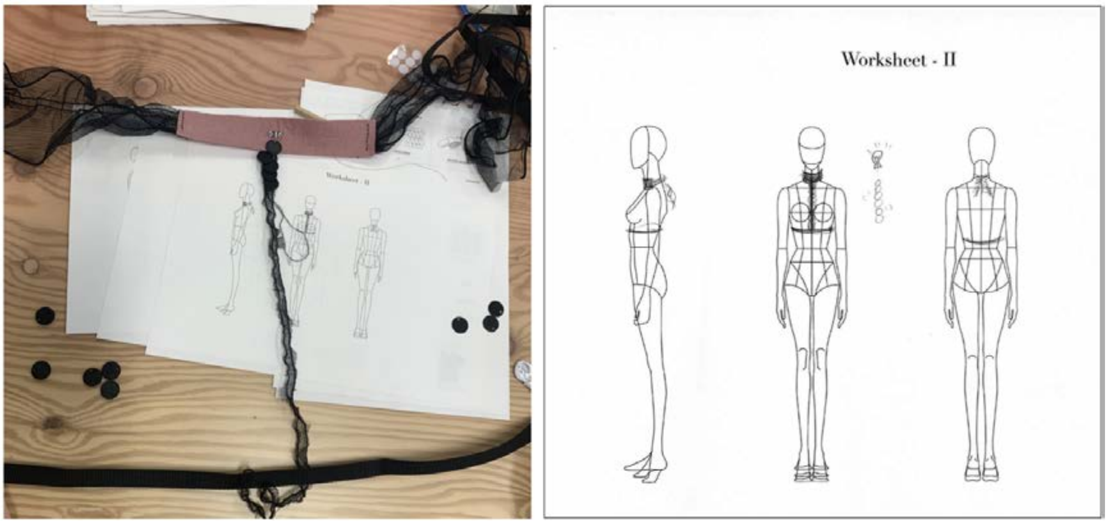

Figure 5.3 Participant B

B would like to design a chest and neck jewelry that can sense body movement. Embroider conductive sequins on the connection belt between the neck ring and the under-bust strap, drive the collision of the sequins through the body movement, and then input the electrical signal generated by the collision into cell phones and other devices, so as to realize the function of sensing body movement(Fig.5.3).

Materials:

Sequins: round partial hole conductive sequins (diameter 15mm, thickness 1mm) textile: pink felt textile, black organza lace, black anti-slip tape

Sewing thread: conductive sewing thread, ordinary black sewing thread

- Participant C:

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Figure 5.4 Participant C

C would like to design a decorative eye mask that can sense muscle movements around the eyes. Two decorative chains made of conductive sequins and non-conductive sequins were attached to a translucent color-changing aurora yarn, and then sewn together with a stretchable textile to form an eye mask. The decorative chain swings with the muscles around the eyes when blinking, and the electrical signal generated by the collision between the conductive sequins is input to cell phones and other devices, thus realizing the function of sensing the movement of the muscles around the eyes(Fig.5.4).

Materials:

Sequins: Pyramid-shaped conductive sequins (S, L); Pyramid-shaped non-conductive sequins (S, M, L)

textile: color-changing aurora yarn, white openwork mesh yarn, khaki fleece

Sewing thread: conductive sewing thread, transparent non-conductive sewing thread

- Participant D:

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Figure 5.5 Participant D

D would like to design a bow that can sense pressure. Embroider conductive sequins on the front and back of the "ear" edge of each layer of the bow, and use beads to decorate the sequins by detecting the contact of each layer of conductive sequins to determine the amount of pressure applied(Fig.5.5).

Materials:

Sequins: round partial hole conductive sequins (diameter 10mm, thickness 1mm)

textile: color changing aurora yarn, laser dazzling mesh yarn

Sewing thread: conductive sewing thread, ordinary black sewing thread

Others: beads

- Participant E:

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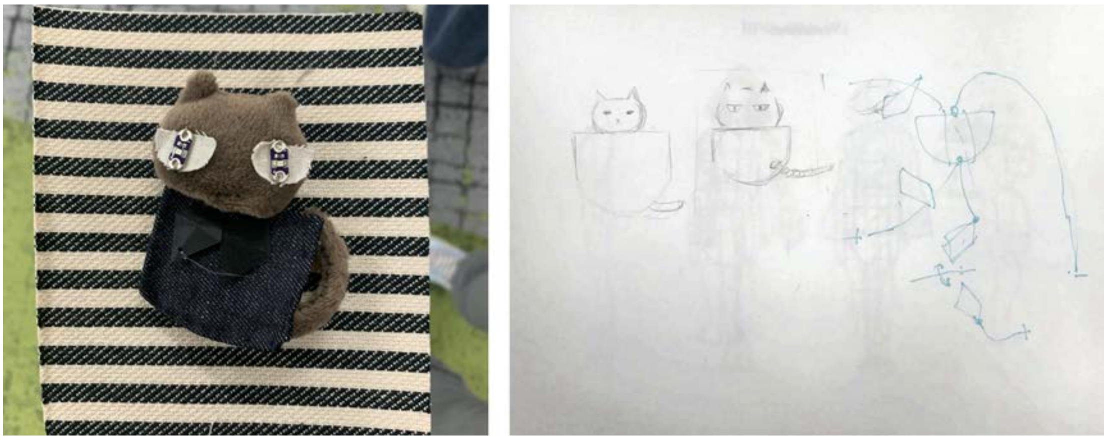

Figure 5.6 Participant E

E would like to design a cat toy brooch that can be interacted with. Sew the LED on the eye position of the cat, embroider the conductive sequins on the cat's chest and connect one of them to the tail part of the cat, control the contact of the conductive sequins by pulling the cat's tail, and thus control the brightness and extinction of the LED(Fig.5.6).

Materials:

Sequins: Pyramid-shaped conductive sequins (S)

textile: khaki fleece, denim

Sewing thread: conductive sewing thread, ordinary black sewing thread

Others: LED

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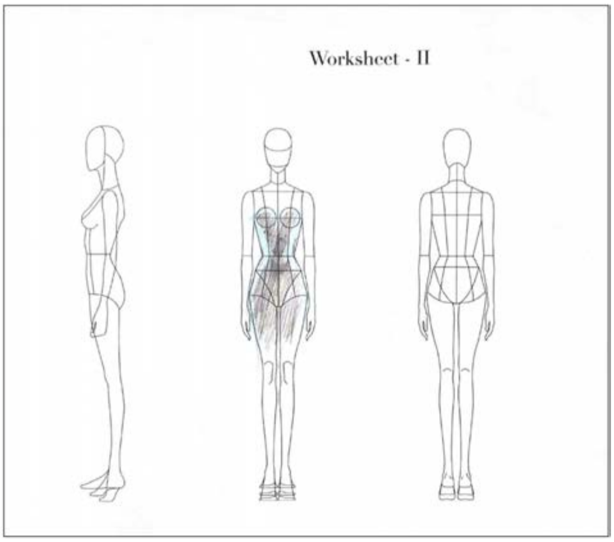

Figure 5.7 Participant F

- Participant F:

  F would like to design an undershirt that can show the body in motion. By embroidering a circle of conductive sequins on the bottom edge of the undershirt, and placing LEDs above each group of sequins (two in a group), and establishing a one-to-one control relationship. As the body swings, the LEDs in different positions can emit light of varying intensity, thus showing the body's state of motion(Fig.5.7).

  Materials:

  Sequins: round partial hole crimped conductive sequins (diameter 10mm, thickness 1mm)

  textile: black satin silk

  Sewing thread: conductive sewing thread, ordinary black sewing thread

  Other: LED

- Participant G:

  G would like to design a raincoat that can show the state of raindrops on the body through light. Use conductive sequins and non-conductive sequins

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Figure 5.8 Participant G

to divide different sensing areas on the surface of the raincoat, and use the property of water conductivity to control the LED on the inner layer of the raincoat with water and conductive sequins, and use the brightness and extinction of the LED to show the effect of rain on the raincoat(Fig.5.8).

Materials:

Sequins: round bias hole crimped conductive sequins (diameter 10mm, thickness 1mm); Round bias hole crimped non-conductive sequins (diameter 10mm, thickness 1mm)

textile: black satin silk

Sewing thread: conductive sewing thread, ordinary black sewing thread

Others: LED

- Participant H:

  H would like to design a sleeve that can sense the movement state of the arm by means of arm loops set in the large arm and small arm respectively. One of the sequins is fixed on the arm ring and the other one can be flipped 180 degrees. The arm ring is sewn with such a group of sequins, and the

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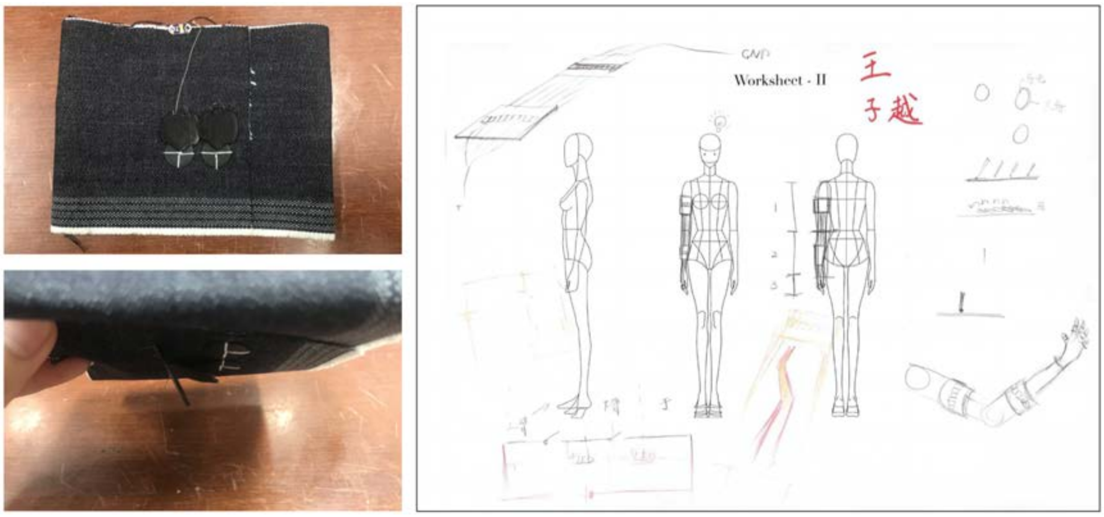

Figure 5.9 Participant H

direction of arm movement is determined by the contact of the sequins at different positions(Fig.5.9).

Materials:

Sequins: round medium-hole conductive sequins (diameter 15mm, thickness 1mm); Scale-shaped double-hole sequins (diameter 20mm, thickness 1.5mm)

textile: denim

Sewing thread: conductive sewing thread, transparent ordinary sewing thread, white rubber thread

Others: LED

5.1.4 Questionnaire and interviews

Questionnaire

From the participants' background research, it is clear that the participants generally have some degree of design and technical background(Fig.5.10).

After about 20 minutes of explanation, everyone basically had a certain understanding of the design space of conductive sequin embroidery smart textile(Fig.5.11).

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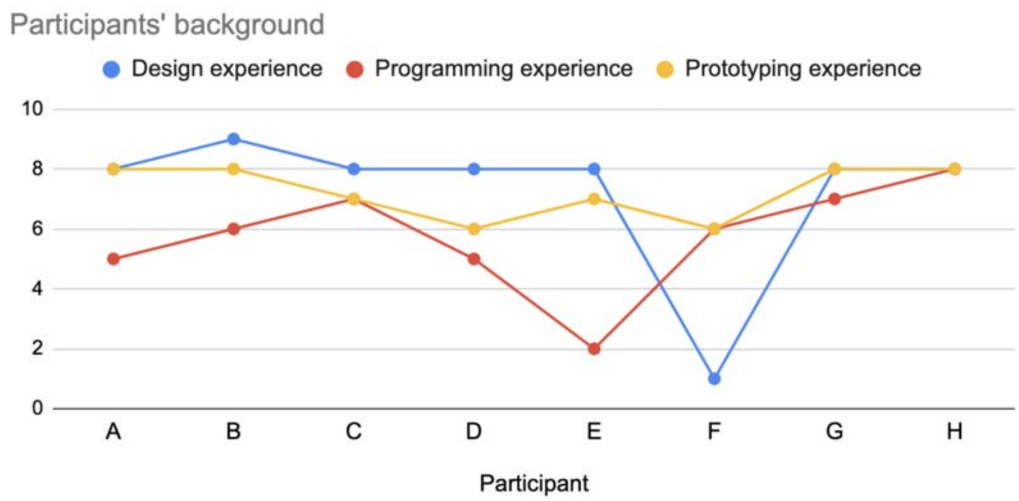

Figure 5.10 Participants' background

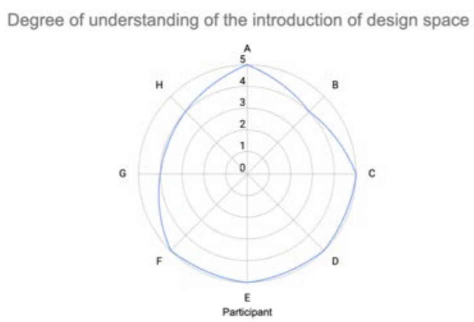

Figure 5.11 Degree of understanding of the introduction of design space

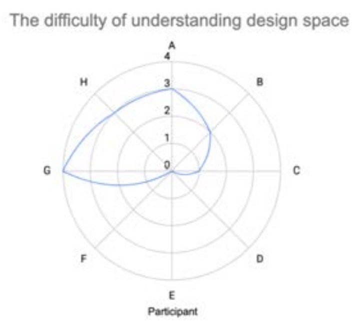

Figure 5.12 The difficulty of understanding design space

And they think it is not very difficult for them to understand(Fig.5.12).

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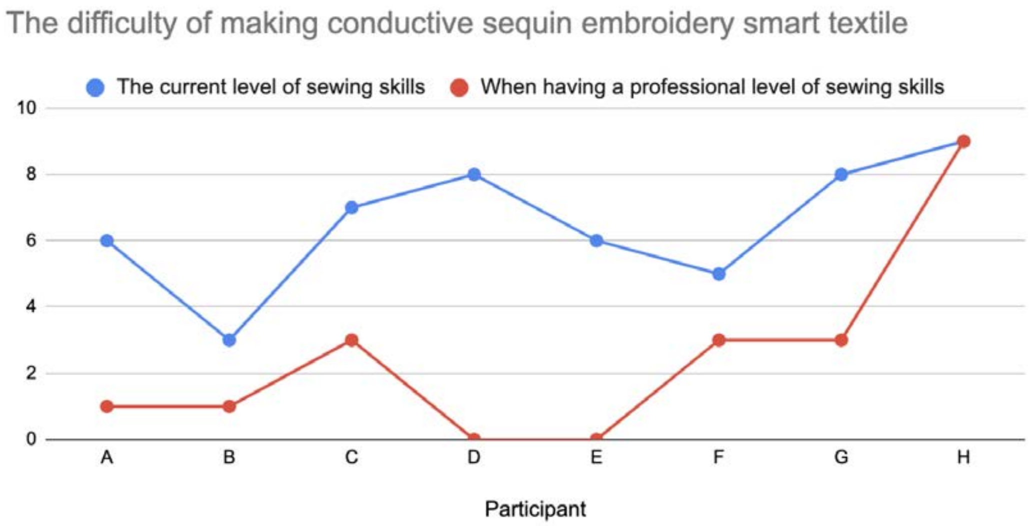

Figure 5.13 The difficulty of making conductive sequin embroidery smart textile

During the production process, everyone had some difficulties in hand sewing due to their different sewing levels, which also resulted in the production taking longer than planned. However, a large percentage of the participants in this project rarely did needlework, and the main reason for the inefficiency was the lack of proficiency, which I believe did not have an undue negative impact on the smoothness of the overall design process. This was confirmed by the responses to the questionnaire: when I asked the participants the hypothesis "How difficult do you think it is to make conductive sequin embroidery smart textile when you all have professional sewing skills", all participants responded with varying degrees of difficulty. I interviewed participant H, whose perception of the difficulty did not change before and after the question, and he said that the difficulty of making the textile did not lie in the sewing technique, but in the process of constant testing and adjustment, and that the skillfulness of sewing did not have much to do with the smoothness of the whole design process. This actually confirms my opinion from another side(Fig.5.13).

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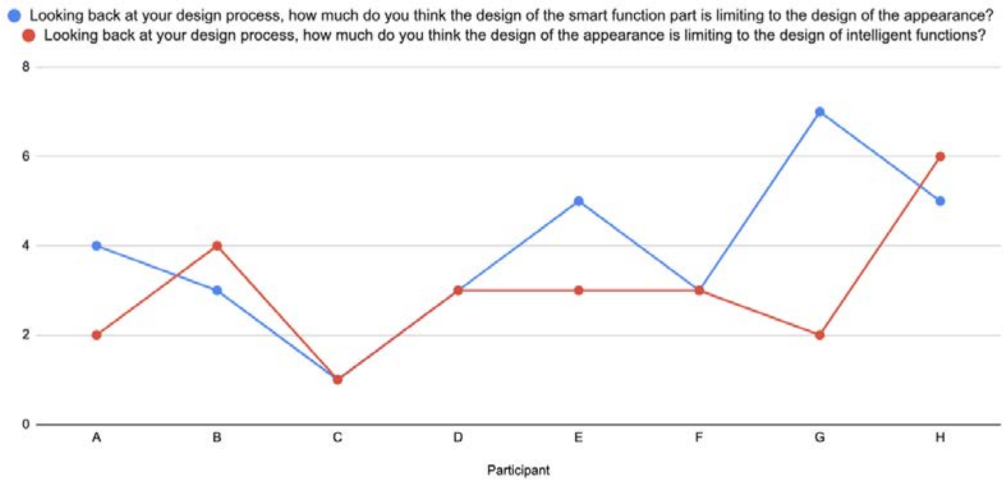

Figure 5.14 The constraint relationship between appearance design and intelligent function design.

Regarding the degree of design freedom, the participants generally thought that the relationship between the design of smart functions and the design of appearance was not very restrictive, and most of the data were concentrated below the average. Among them, 37.5% of the participants thought that the relationship between smart function and appearance was more balanced, another 37.5% thought that smart function had more constraints on appearance in design, and 25% thought that appearance had more constraints on smart function in design(Fig.5.14).Overall, it was felt that this constrained relationship was still relatively manageable.

Regarding the question of design motivation, 25% of the participants especially wanted to continue designing garments with conductive sequins, and even had new ideas in mind, while 75% of the participants said they would continue designing if given the opportunity. This shows that the current design system has a positive effect on designers' design motivation(Fig.5.15).

After the 3.5 hour workshop, 87.5% of the participants were willing to wear the clothing made of conductive sequin embroidered smart textile in their daily lives.

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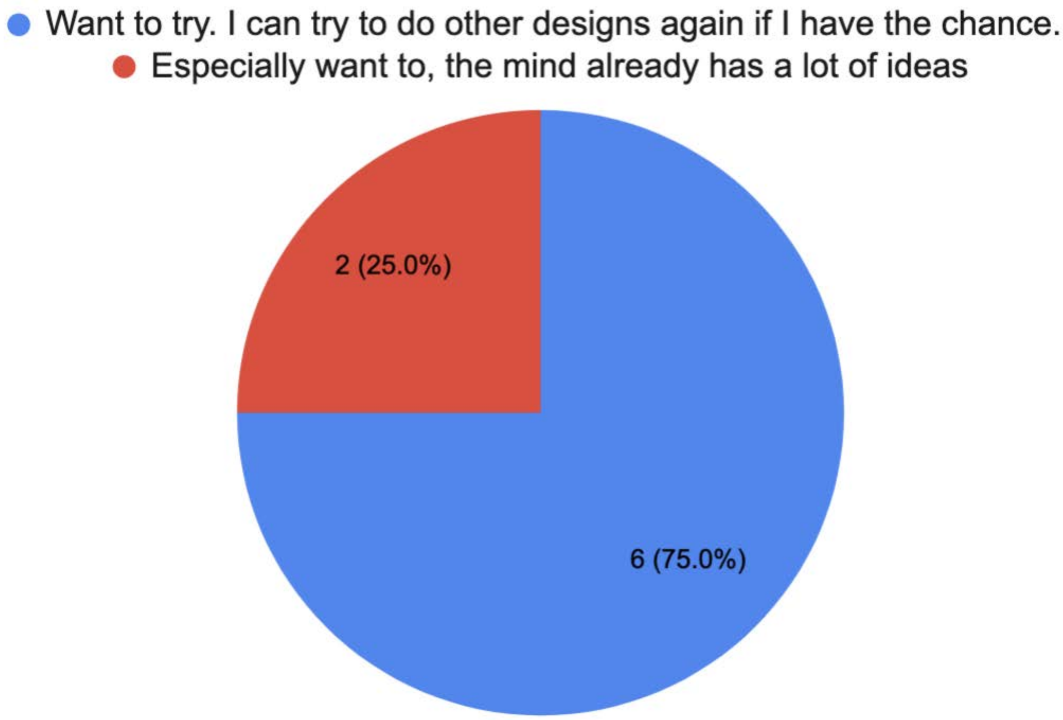

Figure 5.15 After completing this design and production, would you like to continue trying to create other designs?

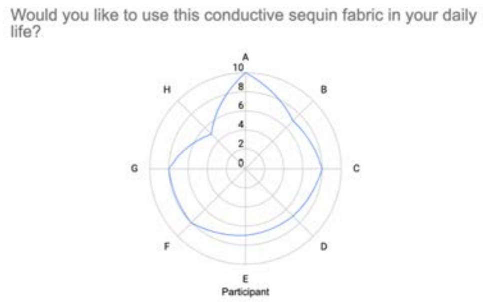

Figure 5.16 Would you like to use this conductive sequin textile in your daily life?

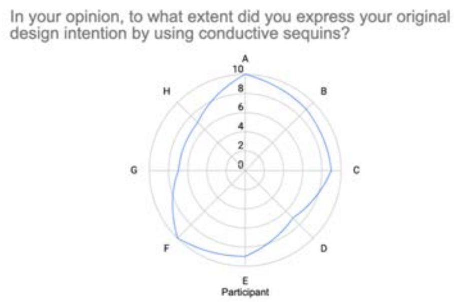

Figure 5.17 In your opinion,to what extent did you express your original design intention by using conductive sequins?

One participant questioned the safety of its use in daily life scenarios and said he would be willing to try it if the safety issue could be solvedFig.5.16).

Finally, I surveyed the participants about the design reproduction of the final product. All the participants thought that the final prototype basically reproduced their original design intentionFig.5.17).

Interviews

I also interviewed several of these participants.

- I thought it was very fun, and having tried to make this smart dress by myself for the first time made me more curious about this field. And I also got some new inspiration through the exchange with others in the workshop, so I hope I have the chance to participate in making it again next time! Although my own work may not be perfect, I'm looking forward to seeing how this will look on my body if I really make it.
- I think this toolkit provides a very good design space, and some other proto types would like to use this to do it, and the process feels like fashion and technology can be well balanced. (The help from the workshop owner when sewing is great, I can enjoy it even if it is not a very high threshold of handicraft)
- Piece by piece sewing is difficult for newbies, I hope to introduce a simpler method in Workshop. Thank you.
- Fun is also very important! And I personally prefer to join the consideration of led can bring the visual effect, concern led and conductive sequins combination can bring the maximum visual freshness

Basically all participants found the workshop very interesting and had a similar introductory effect on their understanding of the field of smart clothing and smart textiles, and aroused their interest in this field. It also gave them more ideas for future designs and enriched their imagination about smart clothing.

Some participants also expressed their wish for easier sewing methods to improve the production efficiency and the aesthetics of the finished products.

5.1.5 Summarization

To sum up, through this workshop, I found out,

- It is possible to understand and practice the design and production of a new smart garment in a relatively short period of time.
- In general, it is considered that the constraint relationship between appearance design and smart function design in the process of making conductive sequin textile is still relatively manageable.
- It had a positive effect on the design motivation of the participants and had a positive impact on everyone's understanding of the field of smart garments and smart textiles.

In looking at the entire workshop process, one area that stood out to me was the question about the degree of automation in design and manufacturing.

On the one hand, there was feedback about the difficulty of hand sewing and the hope that production efficiency could be improved by automated equipment.

But on the other hand, there were also participants who felt the need to deepen their understanding of the characteristics of various materials through hand sewing, and that the development of an automated production system is based on the system developer's understanding of the characteristics of the materials, which may limit the design to some extent.

5.2. Analysis of the connection between design principles and sensing functions

The analysis of Design Space and the actual application on garments allow us to establish a basic link between the design primitives and the sensing function of the conductive sequin embroidered smart textile, as shown in the (figure5.18).

Touch sensing does not require much in terms of shape. Basically, as long as it is made of conductive material, it can basically be successfully implemented.

Pressure sensing is more spatially demanding in the longitudinal direction, and smooth and untextured structures do not sense changes in pressure very well.

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Comparison Table of the Design Primities of conductive sequins embroidery and Sensing Functions

Design Primities		Sensing Functions	Touch	Pressure	Bend	Stretch	Motion Sensing	Switch/ Controller
Sequins	3D Shape	Flat	○	△	△	△	△	○
		Pyramid	○	○	△	△	◎	○
		Curve	○	△	△	×	○	○
		Wavy	○	◎	△	◎	△	○
	Hole Position	Off-set hole	○	○	△	○	○	○
		Center hole	○	△	○	△	×	○
		Multi-hole	○	○	△	○	○	○
	Texture	With Textures	○	○	△	○	○	○
		Without textures	○	△	○	○	○	○
	Material	Only Conductive sequins	○	○	○	○	×	○
		Conductive sequins + Non-conductive sequins	○	○	○	○	◎	◎
Threads	Stretchable threads		○	×	△	△	○	○
	Non-stretchable threads		○	○	○	△	○	○
Fabric	Soft: cotton, silk, etc.		○	○	○	△	○	○
	Hard: organza, linen, etc.		○	○	○	△	○	○
	Single Layer		○	○	○	○	△	○
	Multi-layer		○	○	○	○	○	○
Sewing Method	Fully fixation		○	△	×	×	×	×
	Unilateral fixation		○	○	○	○	○	○

◎ Highly recommended ○ Suitable for use △ Conditional use × Not suitable for use

Figure 5.18 Comparison Table of the Design Primities of conductive sequins embroidery and Sensing Functions

Bend sensing requires a certain degree of combination of various design elements to achieve. For example, a very soft bending sensor can be obtained by using a non-fixed embroidery method with smooth shaped sequins and a center hole punching position, or a snug but rigid bending sensor can be created with wavy sequins and stretchable stitching. The uniform characteristics are: a. Fit to the textile surface, b. The textile has room to bend, and c. The contact stability is guaranteed. As long as these three points are satisfied, we can further develop other bending sensors with more accurate measurements and better appearance according to the design rules proposed in this study.

Stretch sensing is very suitable for wavy structures that can be hooked to each other. By combining elastic textile and appropriate texture, we can obtain a more stable stretchable structure. However, the sewing method must be non-fixed, and the sewing thread must be as non-stretchy as possible, so that the sequins will not be pulled out of place and cause unnecessary errors.

Motion Sensing requires a structure that can maintain a high level of contact stability during the process of colliding with each other, and here I think the shape of a quadrilateral cone with multiple smooth surfaces is most suitable. The friction coefficient can also be increased by adding appropriate textures. The shape of the central hole should be avoided as much as possible here to ensure the flexibility of the conductive sequins. Moreover, the capture of motion involves many sensing points, so a combination of conductive and non-conductive sequins is needed to delineate the sensing area.

As a switch or controller, the conductive sequins can basically perform normal data input functions in a non-fixed sewing state, which provides a huge scope for further design.

5.3. Conclusion

Through the pre-prototyping and post-workshop, we have two outputs.

- A smart textile with more design space, customizable and very diverse interaction methods.
- An easy-to-understand design principle and manufacturing method for fash-

ion designers and crafters.

For the smart textile part, the conductive sequin embroidery textile stretches the structure of the smart textile from two-dimensional to three-dimensional, and different sensing functions can be realized through the flip, collision and interlocking of the sequins. It also allows more freedom in appearance design and performance design.

By using conductive sequins as part of the circuit, the wiring on the textile can be greatly reduced, which can accommodate more complex circuit designs.

Depending on the characteristics of conductive sequins, sequins of different shapes and sizes can be freely arranged and combined, which has realized multiple functions of a single textile and given designers more room for exploration.

The special touch of three-dimensional sequins can divide the functional area and adapt to non-visual operation.

Conductive sequin embroidery can produce large area multi-point sensing systems with high resolution without the need for sophisticated preparation processes, which is very advantageous for future customization and automated manufacturing.

Conductive sequin embroidery textile integrates functionality into decoration, giving fashion design more room to play. It bridges the gap between fashion intelligence and smart device fashion.

For the part of design principles and manufacturing methods, from our validation results, it is a simple and easy set of design principles and manufacturing methods, but it may be accepted differently by designers with different backgrounds. This is a part that needs special attention when building automated design and manufacturing systems in the future.

By establishing a link between textile design and smart function design, we have established a very good introductory design perspective for fashion designers, which has been proven in our Workshop II to have a very positive effect on designers' motivation. I believe this will also be a fresh impetus for the whole smart clothing industry.

5.4. Discussion

The current conductive sequin embroidery textile stretches the structure of smart textile straight in three dimensions, but what other innovations can be made in the three-dimensional structure of the circuit is the new challenge we face. If the conductive sequins can be nested, hollowed out, and other designs to add layers or create a composite structure, new sensing methods may be possible.

The weight and hardness of conductive sequins require us to find more conductive materials with different properties that can be printed. Or, we can laminate other materials with deformation, color change, etc. to increase the properties of conductive sequins.

Smart textiles are generally associated with washing and durability issues. The surface layer of conductive sequins can be cleaned with a simple wipe, but the cleaning of the inner textile requires attention. According to the current structure, the battery and electronic control board can be washed if they are made waterproof, but the durability has not been verified. We will keep an eye on this issue in our future research.

Hand embroidery of conductive sequins is very time-consuming, and we need to find a way to automate the embroidery. Whether the existing sequin sewing machine can accommodate 3D printed sequins with three-dimensional structure and whether the integrated textileation of interlining textile and conductive sequins can be achieved by 3D printing will be tried to be verified in future research.

The wearing comfort of the conductive sequin embroidery textile also needs to be verified, taking into account the daily wearing scenarios while making bold designs.

Chapter 6
Future Works

In this study, I have designed various shapes and sizes of conductive sequins, experimented with several sewing methods, and implemented and visualized them on garments. These different approaches have given us more design perspectives.

For the manufacture of conductive sequin textiles, hand-sewing is highly labor-intensive, which may not be an obstacle for the handyman, but is demanding for the other users. Therefore, a more automated system is necessary, including an easy-to-use design UI and an automatic sequin sewing machine. In addition, I should try more materials to enrich the color and touch of the conductive sequin textile. For example, use a multi-layer openwork structure to add colors to the conductive sequins or make a new colorful conductive sequins-specific filament.

Further, I have visualized the data input, but I need more experimentation to gather feedback on the conductive sequin textile to explore the outside world. For example, using magnetic materials to control the movement of the sequins, or by applying a voltage to make the sequins vibrate, etc., to expand the smart textile's application scenarios in our daily life.

Furthermore, according to the dancer's feedback, this smart textile with real-time feedback on body movements will make her want to interact more with herself and others by wearing it. So I may establish a community by wearing clothing and accessories made of conductive sequin textile to establish a new way of non-verbal communication.

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