WEARABLES COLLECTIVE
WEAVING INNOVATION INTO STAGES OF LIFE
25-26 March 2024, University of California, Davis

Wearables Collective Word Template for short papers

Bine Roth[a]* and Dr Kaori Ueda[b]

[a]Textiles, Royal College of Art, London, United Kingdom; [b]Textiles, Saga University, Kyoto, Japan

*bine.roth@rca.ac.uk

*ka-ueda@kyoto-saga.ac.jp

Wearables Collective, 25-26 March 2024, University of California-Davis
Track I - Soft Systems Applications
Track II - Wearable Product/Technology Applications
Track III - Tangible Human-Computer/Robot Interface Applications
Please choose one track and delete the rest for the submission.

Nishijin weaving and pleating to create textile sensors

Abstract: This paper presents preliminary results from a study on woven pleated electronic textiles (e-textiles) sensors, with a focus on prototyping, 3D structures, and measuring electrical resistance in woven sensors. The research is a starting point for a larger project exploring the interaction between sensors and the human body, investigating how these structures can be utilised in dynamic settings. To date, knitted materials have been most commonly employed in e-textiles, known for their use of a single yarn and high stretchability. This paper serves as an initial exploration into incorporating stretch into woven textiles for the purpose of recording electrical resistance. Initial pleated structures were identified using *Nishijin* weaving to construct pleated conductive materials. The results underscore that a critical factor in using woven pleats as input devices lies in the combination of yarns and the construction of the woven pleat.

Keywords: pleats; e-textiles; sensors; woven

[1] Introduction

This project delves into the nexus between the human body and technology. The impetus for both conceptual and technical advancements arose from a prior exploration comparing Japanese loom structures with Western loom applications in the creation of body-fit materials. The central challenge lies in fabricating a sensor employing *Nishijin* fabric construction, with the objective of crafting sensors that unfold and seamlessly align with the body's movements. These sensors are explored off the body in this paper but will be designed to be worn on the body, being responsive and interacting with and to human motion to track and monitor e.g. healthcare and wellbeing. As per Deleuze's perspective, clothing transcends mere subservience to the body; instead, it evolves into an independent entity, engaging with the body through its folds, enhancing and enriching the bodily experience, rather than merely concealing it (1993). Petri and Greinke mention in their paper that textile sensors, especially pressure and stretch sensors, have been used for a number of years, in particular for health monitoring (2020). Despite advancements in the realm of e-textiles, challenges persist in ensuring the control and stability of textile sensors according to Liang, A. et al (2019). The intention for this paper is to explore materials, techniques, and conductivity of woven pleated textiles to achieve textile sensors. Various techniques of textile pleating were studied, considering aesthetics, performance, and the interactive potential of pleated woven interfaces.

[2] Textile Techniques:

In general, textile processes can encompass fibres with a diverse range of properties, including strength, stretchiness, thermal resistivity, electrical conductivity, and surface characteristics, among others. While the three primary categories of textile manufacture—knitting, weaving, and "nonwoven" production (such as felting, electrospinning, and heat-bonding processes)—are commonly employed to generate flat sheets of fabric requiring subsequent cutting, sewing, gluing, or welding for the creation of three-dimensional objects, knitting possesses the unique potential to achieve intricate shaping with minimal post-processing (Narayanan, V. et al 2018). Notably, textile sensors are predominantly knitted, leveraging knitting's attributes of stretch and flexibility. Having studied knitted textiles, the potential to create three-dimensional structures is more manageable and hence more commonly used within the textile industry.

This paper explores the possibilities of three-dimensional fabric creation through *Nishijin* weaving. In contrast to knitted fabrics, woven textiles are acknowledged for their strength and durability. Initially, we provide an overview of the rationale behind using Japanese *Nishijin* weaving techniques and materials. Subsequently, we comment on the role of pleating structures in supporting sensor creation for woven fabrics. Our research encompasses the integration of embedded sensor technology and textural variations to achieve a range of shape-shifting effects without manipulating textiles after the production. This marks the inception of a larger project aimed at exploring embedding pleated structures into the construction of textiles and investigate into different pleats and constructions to attain more dependable outcomes.

Finally, we discuss future structural guidelines and fabrication parameters to accomplish these objectives, presenting our preliminary findings.

Figure 1 Nishijin woven fabric, warp: polyester and nylon, weft: polyester and silk high twist yarn

Figure 2 Nishijin woven fabric after being dipped into hot water. Stretchability is given due to the high-twist yarn.

[2a] Hatcho Nenshi & Nishijin Weaving

This chapter focusses on materials and *Nishijin* weaving techniques. Materials play a fundamental role in shaping our interactions with the world. Notably, there has been a growing interest in fabricating responsive textiles. Advancements in the fabrication of conductive materials have opened avenues for designing responsive and interactive clothing to monitor our bodies and receive valuable data.

In this context, our investigation focuses on embedding the pleating structure into the weaving process using high-twist yarn. In our former paper, Ueda and Roth highlight the distinctive wet twisting technique employed in *hatcho nenshi,* a process involving significant twisting of silk yarn which shrinks immersed in hot water. *Nishijin* weaving is a Japanese weaving technique which uses *hatcho nenshi* and allows a double cloth structure to create brocade like textures (2023).

Exploring the rationale behind pleating involves the considerations of textiles and movement, and harnessing potential data derived from the body. Pleated structures, as observed in Future Beauty by Akiko Fukai et al., introduce movement into clothing, offering elasticity and wearability whether arranged horizontally or vertically (2010). The interplay between two and three dimensionality is a key aspect in this paper. By incorporating a pleated structure to enable the fabric to shrink into form, the traditional processes of steaming and stitching are eliminated, as described by Paul Jackson in Complete Pleats (2015). According to Colette Wolff, pleats are measured folds formed at the edge of a piece of fabric where they are secured with stitching (1996).

Embedding high-twist yarn into the woven structure allows the material to 'shrink' into the pleated structure. We have investigated into various structures to understand the construction of the woven textile to allow it to fold without mechanical influence. The patterns include conductive thread which are soaked in hot water to shrink into the folds.

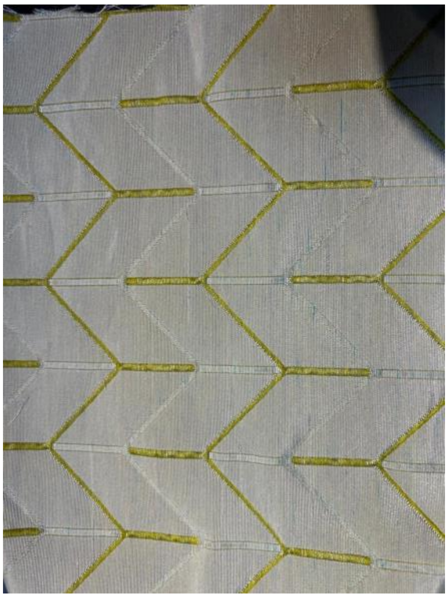

Figure 3 Woven pattern, warp: polyester(white) and nylon (transparent), weft: Bekinox conductive yarn (yellow) and high twist silk

Figure 4 Woven pattern after being dipped in hot water, creating folds

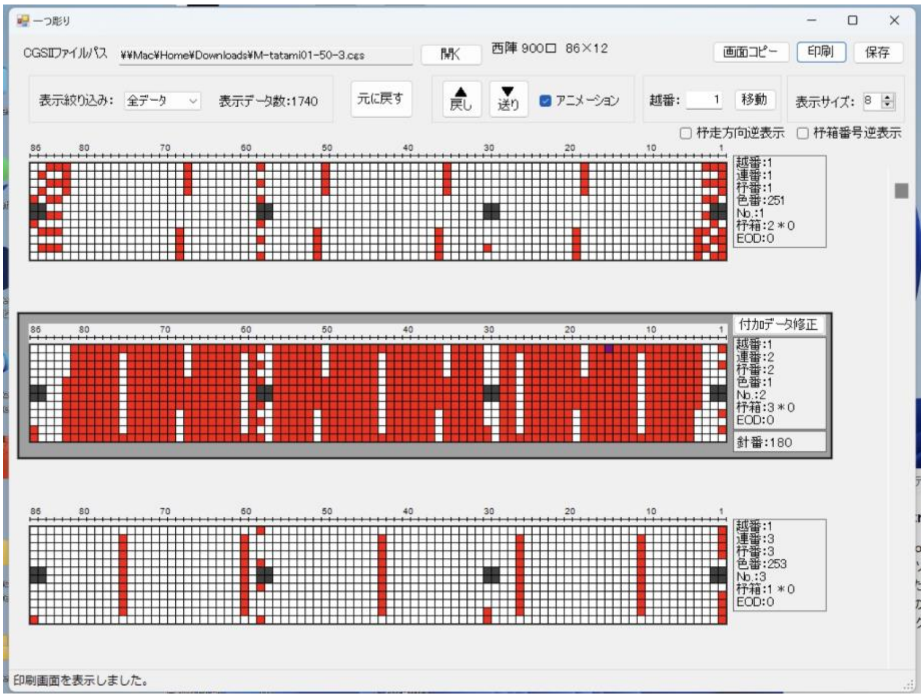

Figure 5 Japanese Jacquard digital data for loom construction, punchcards

[2b] Digital Fabrication for Textiles

In the initial phase of the study, computer programs were employed to develop pleated structures, understanding their flexibility and construction. The goal was to create opportunities for incorporating electronic elements directly into the fabric construction, rather than adding conductive materials afterwards. A series of initial samples were utilised to examine the construction of pleating and the embedding of three-dimensionality into flat-woven fabric.

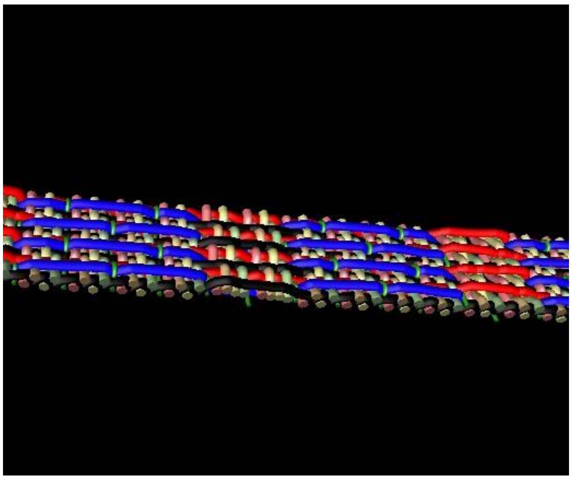

Figure 6 Woven structure simulation using CGII, red & blue conductive thread, black high twist yarn

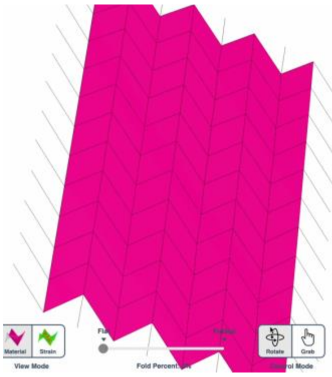

Figure 7 Digital flat pattern, Origami simulator

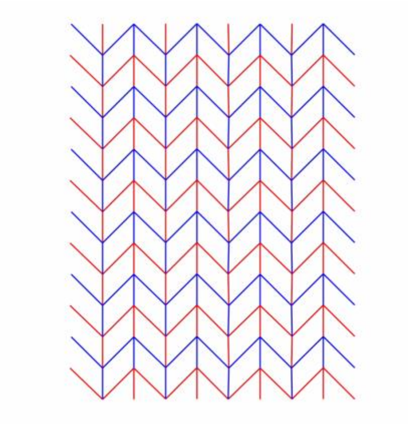

Figure 8 Digital pattern drawing, Origami simulator

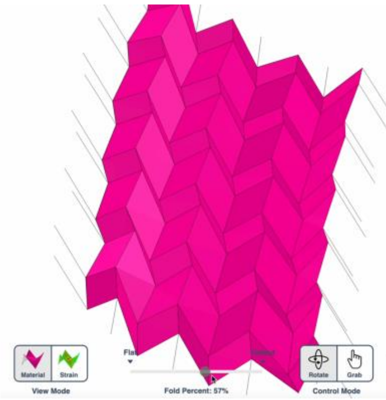

Figure 9 Digital pattern 3D simulation of stretch and shrink, Origami simulator

[2c] Testing and measuring textiles

In this chapter, you can see our exploration of tests aimed at measuring the conductivity of the textiles created through Japanese Jacquard weaving processes. Leveraging multi-material yarns, we embedded conductive components within the fabric. Inspired by the extensive investigations in e-textiles, we would like to introduce two designs of pleated sensors crafted through Japanese Jacquard weaving. Notably, compared with alternative textile techniques such as knitting, weaving imparts a sturdier and more durable quality to the resulting fabric. The strategic application of high-twist yarn allows us to embed stretch into the fabric.

The conductivity was one part of the research, but also the investigation into woven structures becoming soft sensors, focusing on folded textile structures. In the fabric currently under development, we engage in a process of trial and error to create peaks and valleys using *hatcho nenchi* twisted yarn, simultaneously refining the weaving structure. By capitalising on the floating of threads and the pinching effect induced by high-twist yarns, we aimed to develop a fabric that naturally takes shape. Moreover, we explore the prospect of creating two distinct circuits by allowing different yarns to float in the mountain and valley folds.

In addition, the incorporation of shape memory properties, achieved by including polyester in both the warp and weft, emerges as a crucial element in our development. The compatibility of origami structures with shape memory properties due to thermal pressure holds significant promise, and we anticipate the emergence of highly effective structures. We anticipate demonstrating more resilient sensors in the future. The design of specific geometries, such as pleats with conductive yarn, opens avenues for developing various types of sensors.

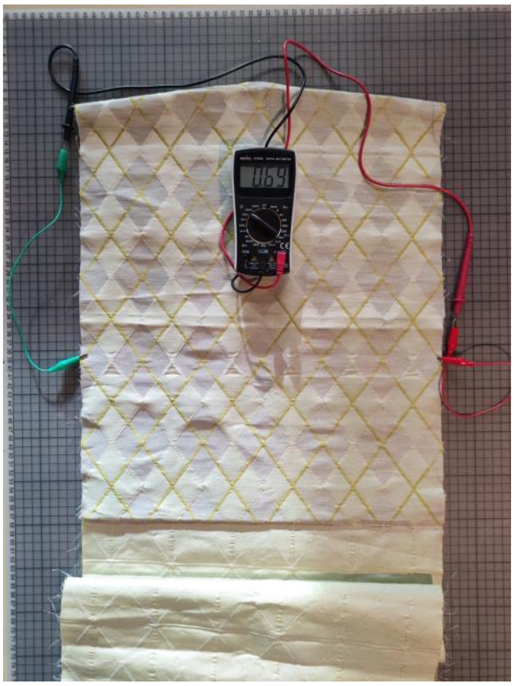

Figure 10 Woven pattern, initial conductive test to explore whether it loses conductivity after sericin being removed

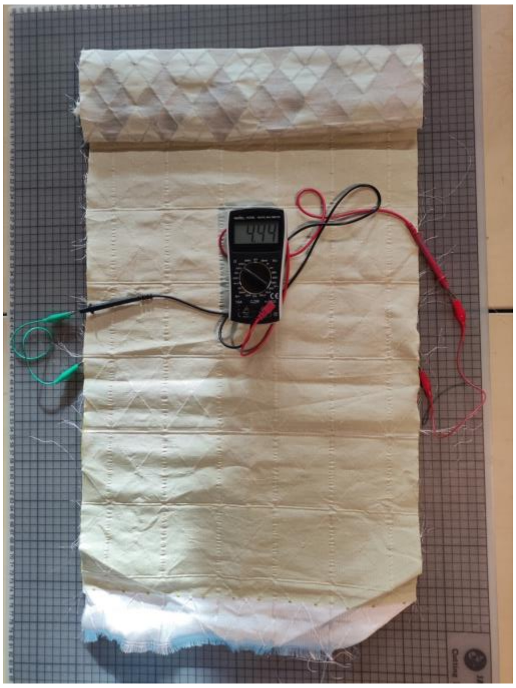

Figure 11 Testing fabric before removal of sericin, warp: polyester and nylon, weft: Bekinox conductive yarn, high twist silk

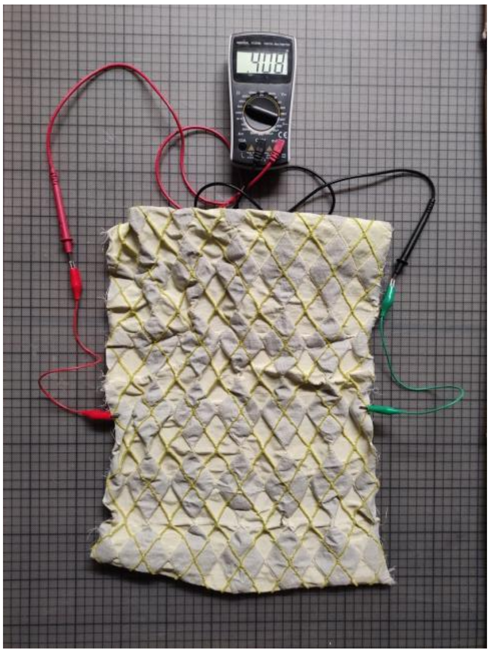

Figure 12 Testing conductivity after removing sericin, slight shrinkage and elasticity noticeable after shrinkage

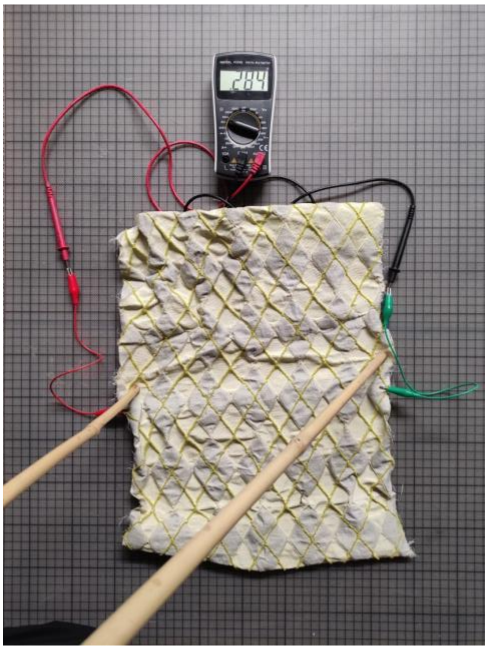

Figure 13 Testing stretch and conductivity change in fabric, slight change noticeable

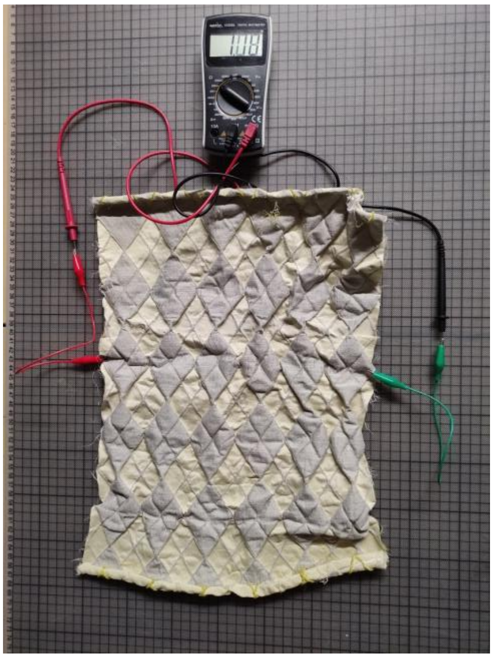

Figure 14 Testing of fabric with grey conductive yarn

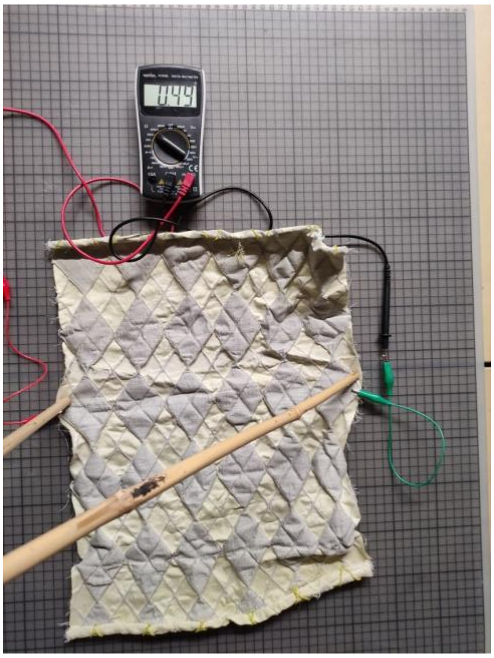

Figure 15 Testing stretch in grey conductive yarn, fabric has had sericin removed, slight difference in conductivity noticeable

Figure 16 Final pleated structure, testing after removing sericin from yarn in stretched capacity

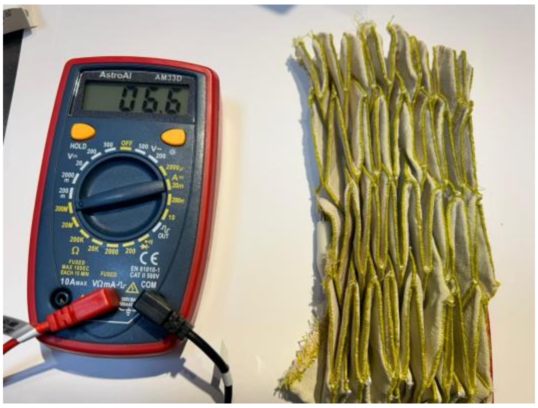

Figure 17 Final pleated structure, testing conductivity in folded capacity

[3] Future applications and comparative analysis knitted versus woven textiles:

Pleated structures have been used within fashion and other fields due to their three-dimensionality and unique properties to expand and stretch. They offer flexibility and adaptability making them ideal for wearable technology applications. We propose for these sensors to be integrated into clothing to monitor body movements or vital signs. The pleated structures allow for localised sensing capabilities due to their defined folds, enhancing the accuracy of data collection. We anticipate for the woven structures to be more accurate than knitted structures due to distinct folds and well-defined patterns. Woven folds are crisper and maintain shapes compared to knitted constructions which can stretch and distort more easily. The refined lines offer intricate patterns that enhance the aesthetic appeal of a product as well. Making them suitable for applications where visual presentation is important.

The interlocking of warp and weft yarns in woven fabrics creates a stable structure that can withstand greater tension and wear over time. As a result, woven textiles can be engineered to provide controlled stretch properties using high-twist yarn. This durability is in particular beneficial in applications such as monitoring devices where the fabric undergoes repeated use or mechanical stress. They conform to the contours of the body, providing continuous monitoring of various parameters. The durability of woven pleats over knitted structures ensures reliable performance even in demanding environments.

We anticipate challenges working with pleated structures, such as the complexity of fabrication and potential issues with conductivity, however the potential advantages are precision, adaptability, and aesthetic appeal to justify further investigations to enquire textiles with durability and tailored functional properties.

[4] Conclusion and future challenges:

In conclusion, this paper has presented the findings from measurements conducted on pleated woven samples, shedding light on the pivotal role of material choices and combinations in designing pleated sensors, where the pleat functions as the input element. The results underscore the necessity for further refinement in both the woven structure and the measurement setup to enhance overall sensor performance, addressing concerns such as noise elimination and connection improvement.

As prototypes take shape, the characteristics of the current weaving machine are integral, yet ongoing research is dedicated to understanding how the weaving structure influences the sharpness of mountain and valley folds. Constructed samples demonstrate though their durability and strength compared to knitted textiles. The test results reveal that the woven pleated structure, influenced by the origami structure, induces changes in the resistance value. Current experiments involve triangular figures with sides approximately 6 cm long, with flexibility in adjusting the figure's size to verify the effects. The origami-inspired structures have the capability to expand however do not distort easily.

Amidst these developments, a significant challenge in designing the sensor matrices arises from the potential loss of conductivity in the top and bottom layers during the finishing process. The removal of the sericin coating from the *hatcho nenshi,* which ‘activates’ the micro-pleats, poses a risk of diminished conductivity in the yarn. Addressing this challenge is critical for ensuring the overall effectiveness of the sensor.

Furthermore, as the scope broadens to include other responsive yarns, the vision extends beyond woven designs solely as sensors, envisioning them as potential actuators. Future applications can range into various areas. This multifaceted role positions woven designs as essential tools in future human-material interaction design. From weaving intricacies to prototype adaptability and challenges in maintaining conductivity, this journey encapsulates the dynamic possibilities and ongoing advancements in the field of interactive textile technology.

[5] Acknowledgements:

We would like to thank our collaborators and supporters Mori-San and Junichiro Horikawa.

References

(1) Deleuze, G. The Fold, 3rd ed.; The Athlone Press: London, UK, 1993.

(2) Fukai, Akiko [et al], Future beauty: 30 years of Japanese fashion, edited by Catherine Ince and Rie Nii, London; New York: 2010.

(3) Jackson, Paul, Complete Pleats, Laurence King Publishing Ltd London, 2015

(4) Liang, A.; Stewart, R.; Bryan-Kinns, N. Analysis of sensitivity, linearity, hysteresis, responsiveness, and fatigue of textile knit stretch sensors. Sensors (Switzerland) 2019, 19, 3618.

(5) Petri, Giorgia & Greinke, Berit. (2021). Measuring Pleated Knitted Sensors. Proceedings. 68. 10. 10.3390/proceedings2021068010. DOI:10.3390/proceedings2021068010

(6) Roth, B.,and Ueda, K.(2023) Generative Nishijin Weaving with and for the body, in Tincuta Heinzel, Delia Dumitrescu, Oscar Tomico, Sara Robertson (eds.), *Proceedings of Textile Intersections Conference 2029*, 20 - 23 September, London, United Kingdom. https://doi.org/10.21606/TI-2023/107

(7) Vidya Narayanan, Lea Albaugh, Jessica Hodgins, Stelian Coros, and James McCann. 2018. Automatic Machine Knitting of 3D Meshes. ACM Transactions on Graphics (TOG) (to appear) (2018).

(8) Wolff, Colette, The Art of Manipulating Fabric, Penguin Random House 1996

Figures:

Figure 1 Nishijin woven fabric, warp: polyester and nylon, weft: polyester and silk high twist yarn created by authors 2024

Figure 2 Nishijin woven fabric after being dipped into hot water. Stretchability is given due to the high-twist yarn created by authors 2024

Figure 3 Woven pattern, warp: polyester(white) and nylon (transparent), weft: Bekinox conductive yarn (yellow) and high twist silk, created by authors 2024

Figure 4 Woven pattern after being dipped in hot water, creating folds, created by authors 2024

Figure 5 Japanese Jacquard digital data for loom construction, punchcards, created by authors 2024

Figure 18 Woven structure simulation using CGII, red & blue conductive thread, black high twist yarn, created by authors 2024

Figure 7 Digital flat pattern, Origami simulator, created by authors 2024

Figure 8 Digital pattern drawing, Origami simulator, created by authors 2024

Figure 9 Digital pattern 3D simulation of stretch and shrink, Origami simulator, created by authors 2024

Figure 10 Woven pattern, initial conductive test to explore whether it looses conductivity after sericin being removed, created by authors 2024

Figure 11 Testing fabric before removal of sericin, warp: polyester and nylon, weft: Bekinox conductive yarn, high twist silk, created by authors 2024

Figure 12 Testing conductivity after removing sericin, slight shrinkage and elasticity noticeable after shrinkage, created by authors 2024

Figure 13 Testing stretch and conductivity change in fabric, slight change noticeable, created by authors 2024

Figure 14 Testing of fabric with grey conductive yarn, created by authors 2024

Figure 15 Testing stretch in grey conductive yarn, fabric has had sericin removed, slight difference in conductivity noticeable, created by authors 2024

Figure 16 Final pleated structure, testing after removing sericin from yarn in stretched capacity, created by authors 2024

Figure 17 Final pleated structure, testing conductivity in folded capacity, created by authors 2024