Fashion and Textiles

RESEARCH

Open Access

Development of digitized evaluation methods for fabric shrinkage and damage using image analysis

Eunbi Yun[1], Sungmin Kim[2] and Changsang Yun[1*]

*Correspondence:
cyun@ewha.ac.kr

[1] Department of Fashion Industry, Ewha Womans University, 52 Ewhayeodae-Gil Seodaemun-Gu, Seoul 03760, Republic of Korea
[2] Department of Textiles, Merchandising and Fashion Design, Seoul National University, Seoul 08826, Republic of Korea

Abstract

The aim of this study is to develop digitalized evaluation methods for fabric shrinkage and damage using image analysis. To develop the shrinkage assessment method, 81 grid dots (nine horizontal lines and nine vertical lines) are introduced into the test fabric. This allows the shrinkage to be verified based on the change in distance between neighboring dots, which not only presents the shrinkage in the warp and weft directions, but also the area shrinkage and skewness. The developed evaluation method yields a value that differs from the actual measured value by less than 1 mm, which confirms its significance. To develop a damage evaluation method using the Original Danish MA test fabric, the change in area caused by loosening threads in five holes is evaluated. The area change in the developed method and the number of loosened threads in the conventional method has a high correlation. Comparing the number of dots in the Poka-Dot test fabric before and after washing enables one to distinguish incorrectly created dots during the manufacturing process and to accurately measure the number of missing dots such that the result is similar to the actual measurement. The accuracy and reproducibility of the developed measurement method are confirmed using various verification such as error rate, washing cycle, and washing time. Digitizing the evaluation method can contribute to the digital transformation of apparel quality evaluation by reducing labor and errors between evaluators.

Keywords: Fabric shrinkage, Fabric damage, Image analysis, Digitalization, Clothes washer

Introduction

Owing to technological developments and market diversification, clothing products have become highly functional and diversified (Topalbekiroğlu & Kübra Kaynak., 2008). In this regard, it is important to maintain the clothes' original function or dimension during the use phase such as washing and drying. For this reason, manufacturers and consumers of clothes washers and dryers are continuously focusing on the management of clothing products (Hill et al., 2011; Sari-Sarraf et al., 2002). In particular, clothes washers may cause deformation and damage to the fabric owing to the effects of water, detergent, and mechanical force during soil removal. The damage caused by washing may be greater than that caused by wear and use (Fan & th thins the fibers of the fabric (McQueen et al., 2017).

To discuss the deformation and damage of fabrics, an accurate measurement method is required (Jasińska., 2019). The standards currently used to measure the fabric shrinkage include AATCC 135 (Test method for dimensional changes of fabrics after home laundering), AATCC 150 (Test method for dimensional changes of garments after home laundering), ISO 6330 (Domestic washing and drying procedures for textile testing), and CAN/CGSB 58 (Textile test methods dimensional change in domestic laundering of textiles)(British Standards Institution, 2001; AATCC Test Method, 2004; CAN/CGSB 4.2, 2004; Zaman et al., 2021; Binjie & Hu, 2008). Standard methods for evaluating the fabric damage, which is also expressed as the mechanical force of a clothes washer or dryer, include ISO 7772-1(Assessment of industrial laundry machinery by its effect on textiles; ISO 7772, 1998). Test fabrics such as nylon fabric to determine mechanical action in the machine (E-304), Poka-Dot (E-307), and Original Danish MA test fabric (MA-24) are typically used (ISO 7772-1, 1998; Talu, 2021; Swissatest Testmaterialien, 2018; Gallen Daniel & Felix, 2011). However, in the existing methods of evaluating the quality of clothing products, the result may vary depending on the measurer's skill, and differences between measurers may lead to inaccurate results. That is, there was a difficulty in obtaining repeatability, reproducibility, and accuracy, which are the basis for evaluation; thus, a method that can objectively and repeatedly evaluate these is needed (Textor et al., 2019). Sari-Sarraf et al. (2002) attempted to improve this issue by developing an image-processing algorithm for the digitization of dimensional stability measurement. In addition, in order to objectively evaluate the retention of fabric shape, an image analysis was used along with simulation of the shape retention process in daily life (Wang et al., 2020).

The aim of this study is to devise methods that can objectively evaluate the fabric shrinkage and damage by minimizing the error factors caused by manual measurements and deviations between measurers, as well as to develop software that can digitize evaluation methods. Digitalized assessments can reduce the measurement time while ensuring reproducibility, repeatability, and accuracy. It will also contribute to improving the reliability of future further studies pertaining to fabric shrinkage and damage.

Methods

Materials

Cotton-washing shrinkage test fabrics (E-320, Testfabrics Inc., West Pittston, PA, USA) were used to evaluate fabric shrinkage. To obtain shrinkage and skewness information for each position of the test fabric, 81 dots, including nine horizontal lines and nine vertical lines at 2 cm intervals, were used in addition to the marks in the existing cotton-washing shrinkage test fabric (E-320). The Original Danish MA test fabric (MA-24, Testfabrics Inc., West Pittston, PA, USA) and Poka-Dot test fabric (E-307, Testfabrics Inc., West Pittston, PA, USA) were used to evaluate fabric damage. For the Original Danish MA test fabric, to observe changes in the area, a concentric circle was drawn at a location 1 cm away from the outer edge of the circle. Figure 1 illustrates the appearance of each measurement test fabric prior to the experiment.

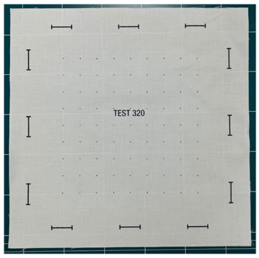
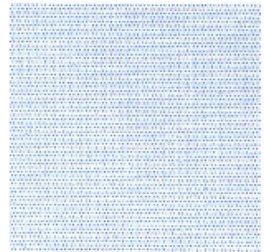
Test fabric	Cotton-washing shrinkage test fabric (E-320)	Original Danish MA test fabric (MA-24)	Poka-Dot test fabric (E-307)
Image			

Fig. 1 Test fabrics for shrinkage and damage measurements

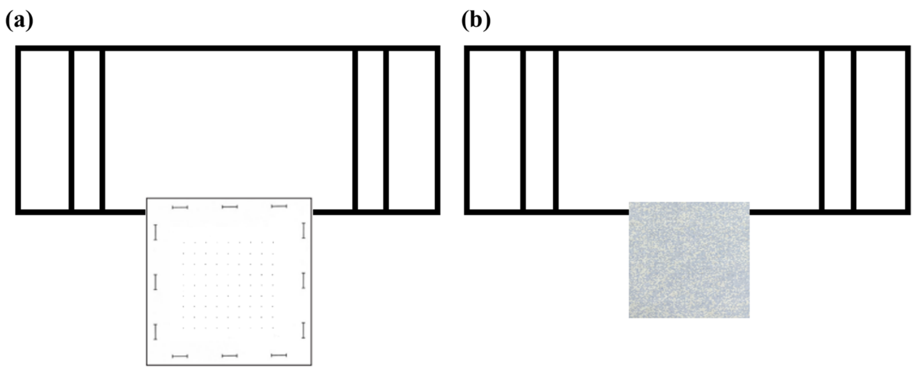


Fig. 2 Attachment of test fabrics; (**a**) cotton-washing shrinkage test fabric and (**b**) Poka-Dot test fabric

Washing process

A front-loading washer (maximum capacity: 24 kg) was used without detergent. Wool, normal, and sanitary cycles were used to vary the mechanical force, time, and temperature. After washing, all fabrics were air-dried. The shrinkage and the Poka-Dot test fabrics were significantly affected by the movement of laundry; accordingly, their top edges were sewn to the bottom edge of the towel, as shown in Fig. 2. The MA test fabric was used without stitching because it was not significantly affected by the fabric movement. Three pieces of each of the three types of samples were washed, and a cotton towel was used as a dummy load to make a total of 2 kg (Cho et al., 2017).

Scan of the test fabric

The test fabric was scanned before and after washing at a resolution of 300 dpi using an Epson WorkForce DS-50000 scanner. The MA test fabric was scanned against a black background to clearly identify the white thread.

Validation of the developed evaluation method

Error validation

An error-verification experiment was conducted to confirm the accuracy of the developed evaluation method. To establish situations of 1%, 2%, 3%, 4%, and 5% shrinkages,

Table 1 Washing conditions for each cycle

Cycle	Washing time (min)	Washing temperature (℃)	Number of rinses	Level of spin speed
Wool	49	Tap water	3	Low
Normal	39	40	2	High
Sanitary	155	95	3	Medium

dots and marks were drawn at the contracted position in the warp direction of the shrinkage test fabric. Subsequently, the degrees of shrinkage measured using a stainless-steel ruler and the developed method were compared and analyzed.

For the Poka-Dot test fabric, the number of dots in the original test fabric was measured using the developed measurement method, and dots corresponding to 1%, 2%, 3%, 4%, and 5% of the number were removed at random locations to verify the error. The yielded values were compared using the measurement values of Image J, a program presented by the manufacturer of Poka-Dot test fabric, △Y, actual values, and the measurement method developed in this study. For the MA test fabric, error verification could not be performed because the principles of the actual measurement and the developed measurement method were different.

Cycle validation

To confirm that the developed evaluation methods can accurately measure shrinkage and damage under various temperatures, times, and mechanical forces, verification was performed using wool, normal, and sanitary cycles, which are the actual consumer usage conditions of the clothes washer. The washing conditions for each cycle are shown in Table 1.

Validation based on washing time

To examine the effect of the mechanical force only, the washing time was changed, and the shrinkage and damage were measured. Based on the normal cycle, 17.7 L of water at 40 °C was used. The washing times were set to 15, 30, 45, and 60 min based on the washing time of the normal cycle (30 min). The washing speed was set to 46 rpm and the reversing rhythm was set to 10 s/10 s (on/off). After washing, fabrics were spin without rinsing and then line-dried.

The experiments for each validation were repeated thrice. When using the developed software, there was no difference between measurers. The actual measurements were conducted individually by three panelists.

Correlation analysis

In terms of damage measurement using the MA test fabric, IBM SPSS Statistics was used for the correlation analysis between the newly developed method using area and the existing method using the number of loosened threads.

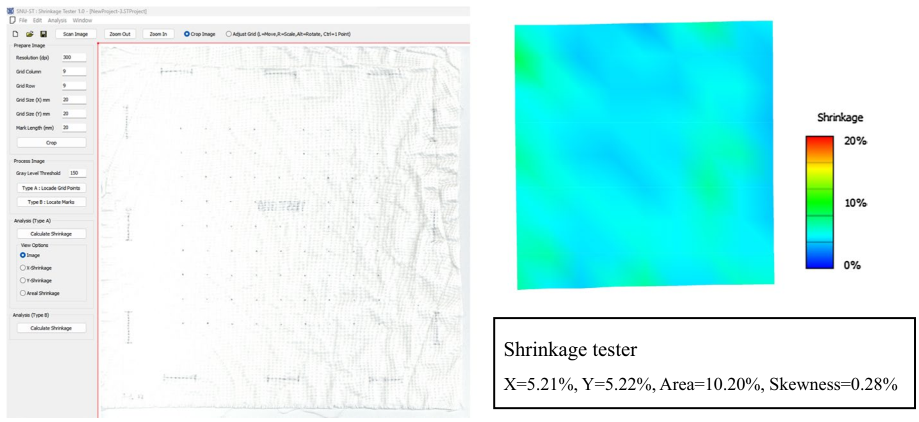


Fig. 3 Example of shrinkage analysis using a fabric shrinkage tester

Results and Discussion

Evaluation idea generation and programming for fabric shrinkage using dots

The existing measurement method using marks can only measure shrinkage at three locations in the warp and weft directions. However, because the variation in the shrinkage of the fabric at each location must be determined, a measurement method using dots was devised to determine shrinkage at all locations. Performing measurements using dots allows one to analyze not only multiple locations, but also multiple directions based on changes in the distance between dots, thereby providing diverse information related to shrinkage compared with conventional methods. Dots are automatically recognized by the software, and if the wrong location is recognized, the measurer can manually change it. Using the dot-based measurement method, as shown in Fig. 3, shrinkage in the warp (Y) and weft (X) directions, as well as the area shrinkage level and skewness value can be obtained. Furthermore, the degree of shrinkage by position can be identified via an image, as shown in Fig. 3.

Evaluation idea generation and programming for fabric damage using loosened threads in holes of MA test fabric

When using the conventional method for the MA test fabric, the number of threads loosened from four sides was counted and evaluated for five holes. However, according to the measurer, the error is significant since the criteria for loosened threads are different for each measurer, and the method of counting broken threads in the evaluation is different. Thus, because the loosened thread was pushed into the hole owing to mechanical force and changes in the area like Fig. 4, the degree of fabric damage was evaluated based on the change in the area of the hole caused by the mechanical force.

When the thread at the edge of the hole was loosened by mechanical force, it occupied the inside of the hole, and the area reduced. At this time, shrinkage or elongation introduced by washing affected the area of the test fabric. Thus, a circle with a radius larger than the hole radius by 1 cm was drawn, and the changed area ratio of the black pixels was calculated based on the circle. This ratio is calculated as follows:

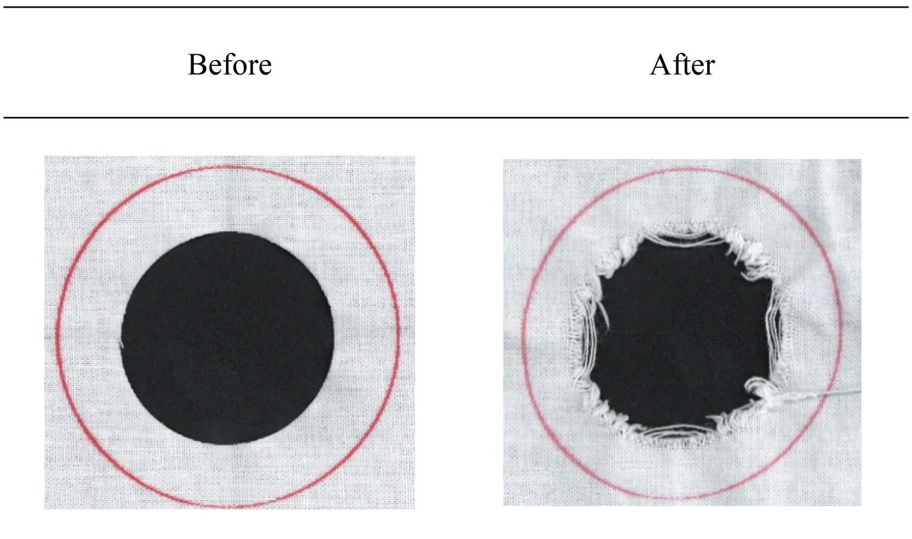


Fig. 4 Area change of MA test fabric before and after washing

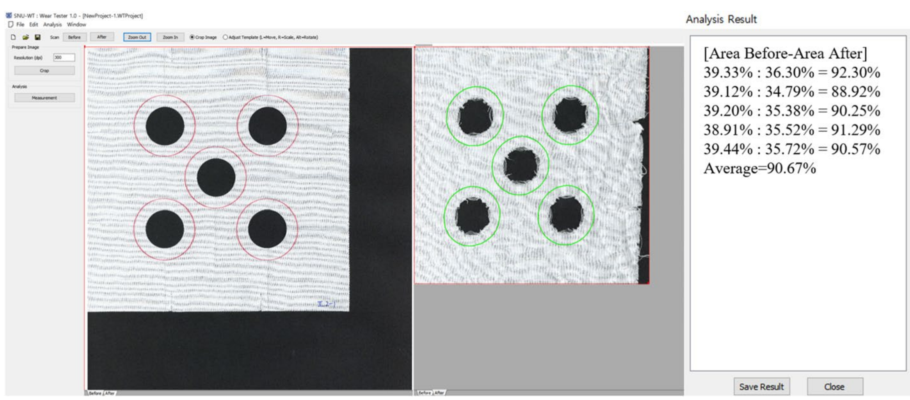


Fig. 5 Example of fabric damage analysis using a fabric damage tester

$$\mathrm{Area_B}(\%) = \frac{\text{Number of pixels in the black area before washing}}{\text{Number of pixels in the total area inside the circle before washing}} \times 100 \quad (1)$$

$$\mathrm{Area_A}(\%) = \frac{\text{Number of pixels in the black area after washing}}{\text{Number of pixels of the total area inside the circle after washing}} \times 100 \quad (2)$$

$$\text{Degree of fabric damage}(\%) = (1 - \frac{\mathrm{Area_A}}{\mathrm{Area_B}}) \times 100 \quad (3)$$

The procedures for using the software that applies the measurement method are as follows. After scanning and imaging the test fabric before and after washing, the software loaded the images, as shown in Fig. 5. The area was captured and cropped to include all five holes. When "Measurement" is selected, the change in the area of black pixels before and after washing and the degree of fabric damage are presented.

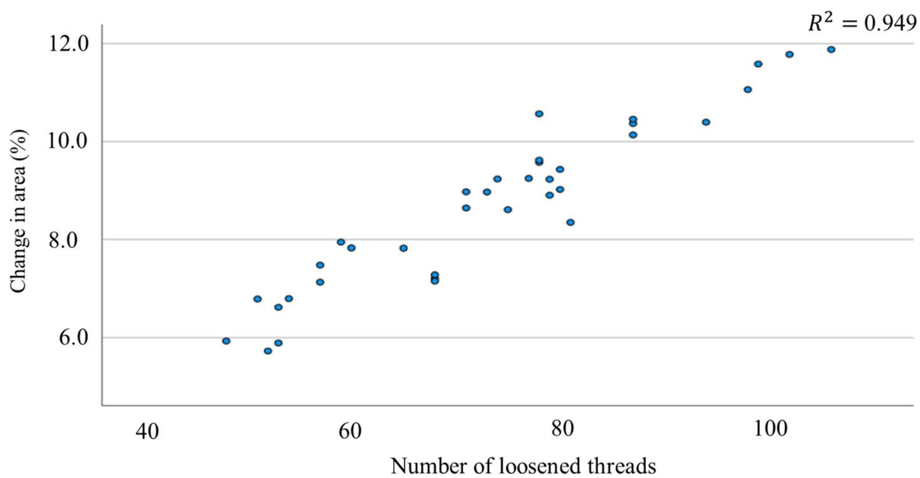


Fig. 6 Correlation between fabric damage based on area change and the number of loosened threads

In the case involving a hole in the MA test fabric, the correlation between the existing method of counting the number of loosened threads and the newly introduced method based on area change was examined. The results obtained for 36 samples are shown in Fig. 6. The correlation between the existing method and the method based on area was indicated by an R^2 of 0.949, which confirmed their significant correlation. The ranking or interval did not match perfectly in the 36 samples because the method based on area included not only loosened warp and weft threads, but also loosened threads at the corner, which can affect the area change. Because the thread loosened at the corner reflects a change due to mechanical force, including it in the evaluation will be meaningful.

Evaluation idea generation and programming for fabric damage using Poka-Dot

The existing evaluation method using the Poka-Dot test fabric is based on the difference in the Y value, which changes depending on whether the dots dropped or the method of recognizing dots using ImageJ software. However, none of these methods could accurately determine the number of dropped dots because some dots are completely or partially eliminated during the manufacturing process, and counting these dots is challenging. The manufacturer of the Poka-Dot test fabric stated that the dot remaining below 30% was considered as a dropped dot. Accordingly, in the proposed method, the pixel occupied by each dot can be calculated such that the dropped dots can be defined according to the above criterion. Furthermore, some dots disappeared prior to washing. Therefore, the images before and after washing were compared to accurately determine the number of missing dots by washing.

In the developed software, as shown in Fig. 7, when the gray level is adjusted, the number of erosion and dilation is entered, and when "Process Image" is selected, the image becomes black and white. Subsequently, the minimum pixel value to be recognized as a dot is entered and counted. If the results before and after are processed in this manner, the number of remaining dots, removal rate, grade, and number by area can be displayed in the resulting window. In this study, the grades were classified as

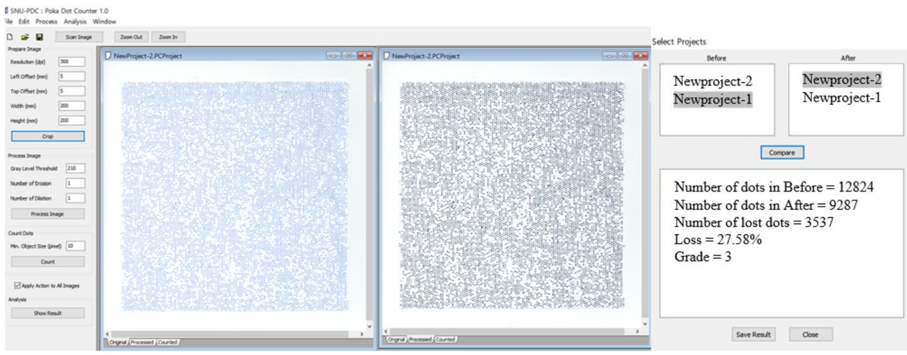


Fig. 7 Example of damage evaluation using Poka-Dot Counter

Table 2 Error verification using a fabric shrinkage tester

Error setting value (Shrinkage, %)	Length (mm)		
	Value by developed software	Value by actual measurement	Difference
1.0	1.1	1.6	0.5
2.0	3.0	3.2	0.2
3.0	5.0	5.3	0.5
4.0	6.3	6.4	0.4
5.0	7.7	8.0	0.4

0–10 based on the preceding data (Gallen Daniel & Felix, 2011). The results could be exported as Excel files.

Error verification

To verify the error between the value yielded by the developed measurement method and the actual measured value, a test fabric for error verification was fabricated and tested. The absolute value of the difference between the two values was defined as the difference to avoid canceling out owing to the sign (positive/negative) associated with the average of the differences.

For the verification of the 1–5% error shown in Table 2, the average difference between the value yielded by the measurement method using the grid point and the actual measured value was 0.4 mm, and the maximum difference was 0.9 mm. This is meaningful result because the error was smaller than 1 mm, which is the smallest unit of the ruler used in the actual measurement. The difference above is due to the fact that the minimum measurement unit of the developed software is 0.085 mm for the size of one dot when using 300 dpi resolution, whereas the minimum unit of the ruler used in the actual measurement is 1 mm. Thus, the developed software can yield more precise measurements.

Figure 8 illustrates the error verification between the results yielded by the developed method and the actual measured value for fabric damage evaluation using the Poka-Dot test fabric. The developed method demonstrated higher accuracy as the result was more similar to the actual measurement compared with the result yielded using Image J and

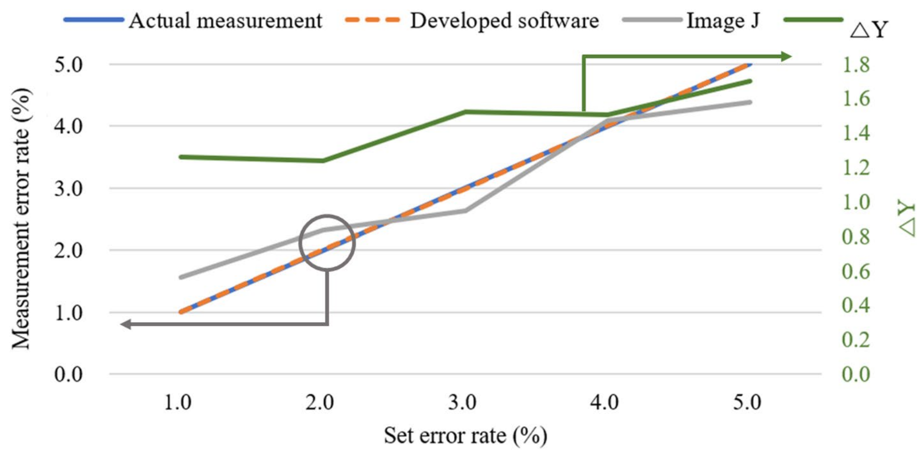


Fig. 8 Error verification using the Poka-Dot counter

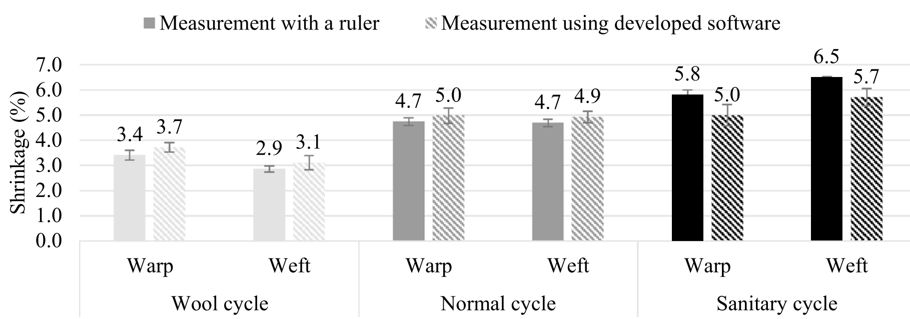


Fig. 9 Verification of fabric shrinkage based on washing cycle

△Y. The average difference between the actual measured value and the value measured using the developed software was 0.02%, which corresponded to two dropped dots, and the maximum difference was four. It was confirmed that accurate measurement is possible within all set ranges. The concept of actual measurement is that the measurer directly counts all dots that have dropped. A total of 2 h was required to count the number of 5% dropped dots, which can in fact be completed in 1 min using the developed measurement method.

Verification based on washing cycle

In addition to the previous error rate verification, to examine whether the developed measurement methods can be applied to various cycles, they were verified using wool, normal, and sanitary cycles, which were assumed to exhibit different mechanical forces and washing temperature in a clothes washer. Figure 9 illustrates the results of the cycle verification of shrinkage evaluation using grid dots. In all cycles, the average difference between the developed measurement method and the actual measured value was 0.23% (at a level of 0.37 mm), which corresponded to less than 1 mm, i.e., the smallest unit of the ruler used in the actual measurement. Thus, the developed method can be used to evaluate a fabric shrinkage at a level similar to that of the actual measurement method in cycles at various temperatures and mechanical forces.

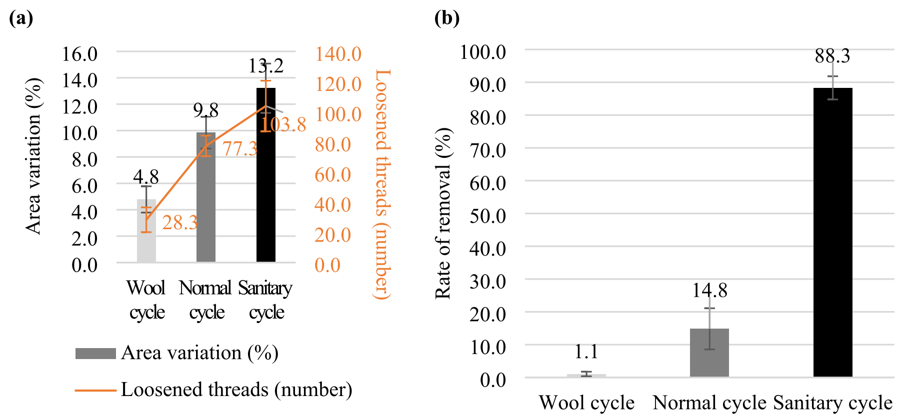


Fig. 10 Verification of measuring fabric damage based on washing cycle; (**a**) MA test fabric and (**b**) Poka-Dot test fabric

The results of the fabric damage measurement using the MA test fabric based on cycles are shown in Fig. 10a. The wool, normal, and sanitary cycles indicated area changes of 4.8%, 9.8%, and 13.2%, respectively. These results show that the developed method can be applied to various washing cycles. When comparing with the number of loosened threads, a similar trend was observed, thus confirming the significance of the developed measurement method.

Figure 10b shows the results of the fabric damage evaluation method using the Poka-Dot test fabric based on the washing cycle. The wool, normal, and sanitary cycles showed removal rates of 1.1%, 14.8%, and 88.3%, respectively. Higher mechanical forces are associated with higher removal rates. Additionally, the evaluation method can be used under various washing cycles and clearly indicate the difference between normal and sanitary cycles. It is thought that not only the mechanical force applied to the Poka-Dot fabric, but also the washing temperature affected the bonding strength between the polymer forming the Poka-Dot and substrate fabric. The sanitary cycle featured a relatively high washing temperature compared with the other cycles. Accordingly, the difference by cycle indicated by using Poka-Dot was greater than that indicated by using the MA test fabric.

Verification by washing time

Based on the cycle verification, it was found that temperature affected the evaluation of fabric damage. To exclude this possibility, the degree of fabric damage and shrinkage was evaluated by changing the washing time at the same temperature. The washing times were set to 15, 30, 45, and 60 min. Figure 11 shows the results of shrinkage evaluation based on washing time. The maximum difference between the results yielded by the developed measurement method and the actual measurement was 0.52% (at a level of 0.82 mm). The resulting values yielded by the actual measurement method and the developed measurement method show a similar tendency, i.e., similarly to the actual measurement, the developed method can distinguish the differences in shrinkage for various mechanical forces.

The results of examining the fabric damage over time are shown in Fig. 12. In the results using the MA test fabric, the changes in area were 7.6% at 15 min and 10.3%

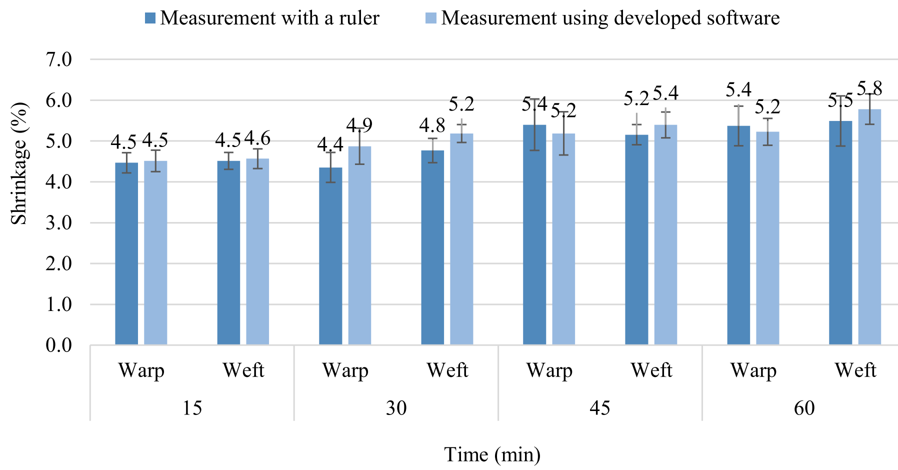


Fig. 11 Shrinkage verification based on washing time

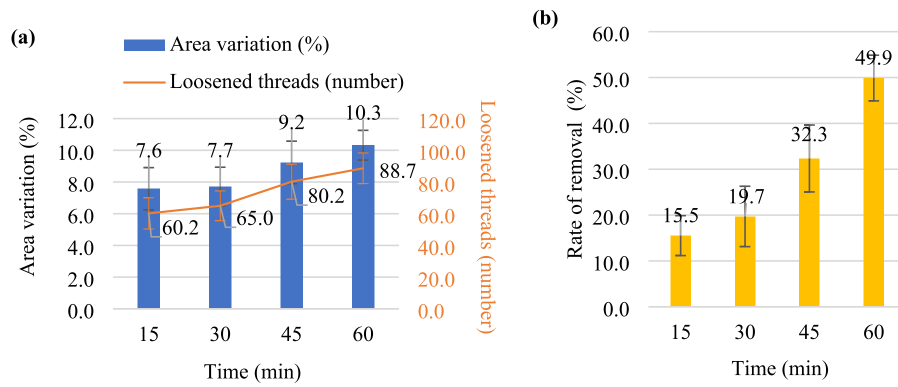


Fig. 12 Verification of fabric damage based on washing time; **a** MA test fabric and **b** Poka-Dot test fabric

at 60 min, indicating significant differences over time. The number of loosened threads showed a similar trend. In the results using Poka-Dot test fabric, removal rates of 15.5% and 49.9% were indicated for durations of 15 and 60 min, respectively. When the results of the two experiments were compared, it appeared that the results based on the magnitude of mechanical force differed depending on the type of test fabric. In the case of the MA test fabric with a hole, the results were discriminative between 30 and 45 min. On the other hand, in the case of the Poka-Dot test fabric, a significant change occurred in the time period between 45 and 60 min.

Conclusions

The aim of this study was to develop and digitize a new method for accurately evaluating fabric shrinkage and damage. Using grid points, the shrinkage in various directions as well as in the conventional warp and weft directions can be measured, and the area shrinkage and skewness can be provided. Additionally, an image map that can intuitively show the fabric shrinkage based on the location can be provided. The developed method is significant because it yields values that differ from the actual measured values by less than 1 mm, which is less than the minimum unit of the ruler used in the actual measurement.

To evaluate fabric damage using the MA test fabric, a measurement method was devised based on the change in area due to mechanical force instead of the number of loosened threads, which may vary depending on the measurer. This is because when the threads at the edge of the hole are loosened owing to mechanical force, they occupy the inside of the hole, and the area is reduced. This highly correlated with the results of the existing evaluation method using the number of loosened threads. In measuring the fabric damage using the Poka-Dot test fabric, dots that were made incorrectly during the manufacturing process were made to be perfectly distinguished, which allowed them to be expressed as the value most similar to the actual number of dropped dots; this could not be achieved using Image J software and $\triangle$Y, which are the existing evaluation methods. In addition to the number of dropped dots, the removal rate, grade and dropout information based on location were provided, thereby enabling a multifaceted analysis of the fabric damage. Additionally, fabric shrinkage was accurately measured using the dots. Thus, in creating a test fabric such as the Poka-Dot, if the substrate fabric and the polymer-constituting dots can be combined well, then the fabric shrinkage and damage can be measured simultaneously.

An error verification was conducted to evaluate the accuracy of the developed methods. To confirm their application, verification was conducted under wool, normal, and sanitary cycles at different washing temperatures and mechanical forces. To examine the effect of only mechanical force excluding temperature, additional verification was conducted under different washing times.

By developing a digitalized measurement method, the error between measurers can be reduced through precise and highly accurate results. This is expected to be effective in securing reproducibility and repeatability as well as reducing labor, cost, and time.

Acknowledgements
Not applicable.

Authors' contributions
EY conceived the ideas, experimental design, performed the experiments, collected the data, interpretation of the results, and drafted the manuscript of the analysis. SK gave support to the creation of new software used in this study. CY supervised on the experimental design, experimental results, and manuscript preparation. All authors read and approved the final manuscript.

Funding
This study was conducted with the support of LG Electronics (No. 2-2021-1688-001-1).

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 13 February 2023 Accepted: 27 May 2023
Published online: 25 June 2023

References

AATCC Test Method 135-2004. (2004). Dimensional changes of fabrics after home laundering. https://members.aatcc.org/store/tm135/543/

Binjie, X., & Hu, J. (2008). Fabric appearance testing. In H. Jinlian (Eds.), *Fabric testing* (pp. 148–188). Woodhead Publishing.
British Standards Institution, BS EN ISO 6330:2001. (2001). Textiles – Domestic washing and drying procedures for textile testing. https://www.iso.org/standard/43044.html
CAN/CGSB 4.2 No. 58:2004. (2004). Textile test methods - dimensional change in domestic laundering of textiles. https://publications.gc.ca/site/eng/9.880083/publication.html
Cho, Y., Yun, C., & Park, C. H. (2017). The effect of fabric movement on washing performance in a front-loading washer IV: under 3.25-kg laundry load condition. *Textile Research Journal, 87*(9), 1071–1080. https://doi.org/10.1177/0040517516648508
Fan, J., & Hunter, L. (2009). *Engineering Apparel Fabrics and Garments*. Woodhead Publishing.
Gallen Daniel, F., & Felix, F. (2011). Article 306 / 307 "POKA DOT" Test Fabric for Mechanical Action. EMPA Testmaterialien AG. https://www.swissatest.ch/en/downloads/documentation/test-materials.html
Hill, M., Kamalakannan, S., Gururajan, A., Sari-Sarraf, H., & Hequet, E. (2011). Dimensional change measurement and stain segmentation in printed fabrics. *Textile Research Journal, 81*(16), 1655–1672. https://doi.org/10.1177/0040517511407378
ISO 7772-1. (1998). Assessment of industrial laundry machinery by its effect on textiles—part 1. Washing machines. https://www.iso.org/standard/14640.html
Jasińska, I. (2019). The algorithms of image processing and analysis in the textile fabrics abrasion assessment. *Applied Sciences, 9*(18), Article 3791. https://doi.org/10.3390/app9183791
McQueen, R. H., Batcheller, J. C., Moran, L. J., Zhang, H., & Hooper, P. M. (2017). Reducing laundering frequency to prolong the life of denim jeans. *International Journal of Consumer Studies, 41*(1), 36–45. https://doi.org/10.1111/ijcs.12311
Sari-Sarraf, H., Hequet, E. F., Abidi, N., Dai, Y., & Chan, H. Y. (2002). Automatic measurement of fabric shrinkage. *AATCC REVIEW, 2*, 20–23. https://doi.org/10.1117/12.460186
Swissatest Testmaterialien. (2018). https://www.swissatest.ch/en/downloads/documentation/test-materials.html
Talu, M. F. (2021). Automatic measurement of shrinkage rate in denim fabrics after washing. *Tekstil Ve Mühendis, 28*(123), 191–198. https://doi.org/10.7216/1300759920212812304
Textor, T., Derksen, L., Bahners, T., Gutmann, J. S., & Mayer-Gall, T. (2019). Abrasion resistance of textiles: Gaining insight into the damaging mechanisms of different test procedures. *Journal of Engineered Fibers and Fabrics, 14*, Article 1558925019829481. https://doi.org/10.1177/1558925019829481
Topalbekiroğlu, M., & Kübra Kaynak, H. (2008). The effect of weave type on dimensional stability of woven fabrics. *International Journal of Clothing Science and Technology, 20*(5), 281–288. https://doi.org/10.1108/09556220810898890
Wang, L., Tang, Q., Zhang, X., & Gao, W. (2020). Instrumental evaluation of fabric shape retention by image analysis. *Textile Research Journal, 90*(21–22), 2376–2384. https://doi.org/10.1177/0040517520921505
Zaman, S. U., Tao, X., Cochrane, C., & Koncar, V. (2021). E-textile systems reliability assessment—A miniaturized accelerometer used to investigate damage during their washing. *Sensors, 21*(2), 605. https://doi.org/10.3390/s21020605

Publisher's Note

Eunbi Yun EY received a Master degree from the Department of Fashion Industry at Ewha Womans University in 2023. She currently works at the Korea textile trade association.

Sungmin Kim SK is a Professor of Fashion Technology in the Department of Fashion and Textiles at Seoul National University. He holds a Ph.D. in Material Science and Engineering from Seoul National University. His research focuses on the intersection of clothing science and technology, with a particular emphasis on integrating information technology (IT) into the field.

Changsang Yun CY is an Associate Professor in the Department of Fashion Industry at Ewha Womans University. He received a Ph.D. from Seoul National University. His research group is to explore the textile-based science & technology for sustainable fashion.