Yarn Segmentation from 3-D Voxel Data for Analysis of Textile Fabric Structure

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Abstract: In this paper, a novel method for analyzing a textile fabric structure is proposed to segment each yarn of the textile fabric from voxel data made out of its X-ray computed tomography (CT) images. In order to segment the each yarn, directions of fibers, of which yarn consists, are firstly estimated by correlating the voxel with a fiber model. Second, each fiber is reconstructed by clustering the voxel of the fiber using the estimated fiber direction as a similarity. Then, each yarn is reconstructed by clustering the reconstructed fibers using a distance which is newly defined as a dissimilarity. Consequently, each yarn of the textile fabric is segmented from the voxel data. The effectiveness of the proposed method is confirmed by experimentally applying the method to voxel data of a sample plain woven fabric, which is made of polyester two folded yarn. The each two folded yarn is correctly segmented by the proposed method.

Keywords: analysis of textile fabric structure, yarn segmentation, X-ray computer tomography, three-dimensional fiber model matching method

1. Introduction

In textile industries, there is a work to analyze textile fabric structures. Although this work makes an important contribution to textile designs, it still relies on a conventional inspection, which is accomplished by human with the help of microscopes and tweezers. Now this work has become a very tedious and time-consuming work because textile fabrics with intricate structures have appeared in recent years. An automatic analysis of textile fabric structures is required accordingly.

Some researches for the automatic analysis of textile fabric structures were reported[1], [2], [3]. For example, Huang et al.[4] identified weave patterns of woven fabrics based on geometric features of yarn distribution after located yarns and their crossover points based on the maximum and minimum gray-level sums of the horizontal and vertical pixel lines over an entire image of the woven fabric surface. Kondo et al.[5] discriminated stitch shapes for analysis of the stitch construction of knit fabrics using a template matching method. In these researches, however, analyses of intricate textile fabric structures such as three-dimensional textile fabric ones cannot be analyzed because all the researches are based on their surface images, from which sufficient information for the analysis cannot be obtained.

For analyzing the intricate structures of textile fabrics, we have proposed an analysis method of textile fabric structures with its cross-sectional images. In our previous study[6], we used the cross-sectional images obtained by cutting and grinding the sample fabric fixed by a resin, which is conducted by manual operation. This analysis, however, was destructive analysis because the sample fabric was cut and grinded. In our recent study[7], [8],the cross-sectional images, which are taken by an X-ray CT scanner, are used. The advantage of this study using the CT images is a non-destructive analysis in addition to automatic operation. The CT images are additionally used as 3-d voxel data in order to analyze the structure three-dimensionally. The target textile fabric of this study is, however, limited to the ones using single yarns, of which cross-sectional shape is less likely to be deformed. The proposed method for analyzing the structure had some issues including a deformation of the yarn cross-sectional shape.

In this paper, we discuss a method resolving the issues for analyzing more intricate structures than the ones, which have ever been targeted in the previous study.

2. Analysis of textile fabric structure

In this study, an analysis of a textile fabric structure means to segment each yarn of a sample textile fabric from the voxel data made out of the CT images, which is an objective of this study. Segmenting the yarn is useful for analyzing a textile fabric structure. For example, particular yarns can be independently expressed using the information of the each segmented yarn. Shown in Fig.1 and Fig.2 are structures of the same twill fabric respectively. The twill structure of Fig.1 is reconstructed by accumulating its CT images directly, while the twill structure of Fig.2 is reconstructed from the information of the each segmented yarn. Although the appearances of the both figures are almost the same each other, the each yarn can be independently expressed in the later reconstruction as shown in Fig.3, which is available for analyzing how a textile fabric is woven.

3. Previous study and its issue

In our previous study, the yarn is segmented by obtaining positional information of each yarn. The positional information of each yarn is obtained by tracing the each yarn, which is equivalent to estimating a sequence of core points of each yarn because the sequence can be considered as a sequence of representative points of yarn position.

3.1. Three-dimensional yarn model correlation method

For tracing each yarn, we proposed a method to estimate the direction of a yarn in a calculating region, which is called

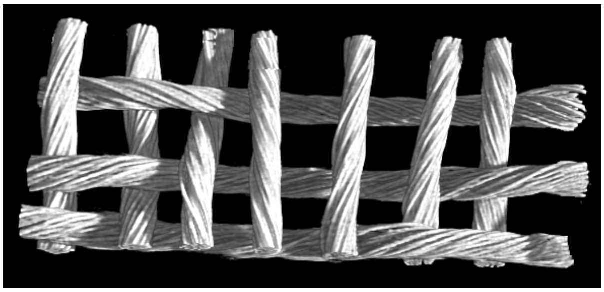

Fig. 1. Twill fabric structure reconstructed by accumulating its CT images directly

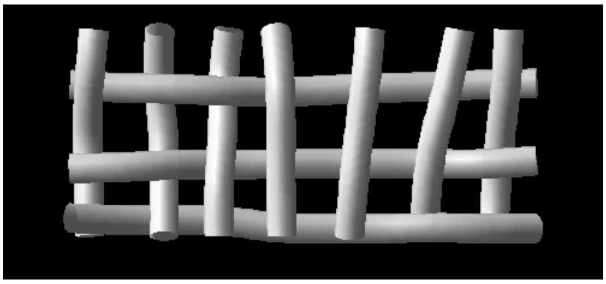

Fig. 2. Twill fabric structure reconstructed from information of each segmented yarn

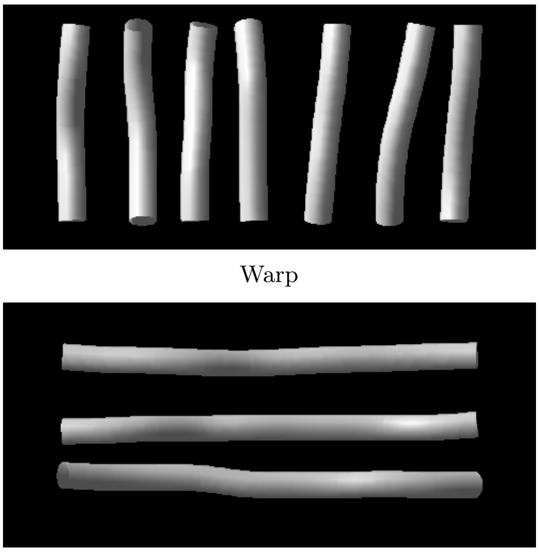

Fig. 3. Independent expression of each yarn

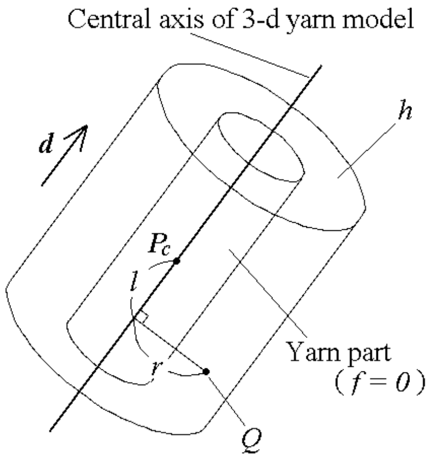

Fig. 4. Correlation of voxel data made out of CT images of yarn and 3-d yarn model in calculating region

three-dimensional (3-d) yarn model correlation method in our previous study. In the calculating region a yarn can be regarded as straight. In this method, the voxel data made out of sample textile fabric CT images in the calculating region are correlated with a 3-d yarn model by

$$J_3(\boldsymbol{d}) \quad = \quad \sum_V h(r)f(i,j,k), \tag{1}$$

where $\boldsymbol{d}$ is a normalized direction vector of the 3-d yarn model, V is the calculating region, h is the 3-d yarn model which is column in this study, f is binarized voxel data made out of its CT images, which has 0 on the yarn part while 1 on the background part, and r is a distance from a calculating point Q to the central axis of the 3-d yarn model which is represented as follows:

$$r(\boldsymbol{Q},\boldsymbol{d}) = \sqrt{|\boldsymbol{Q}-\boldsymbol{P}_c|^2 - |(\boldsymbol{Q}-\boldsymbol{P}_c)\cdot\boldsymbol{d}|^2}, \tag{2}$$

where $\boldsymbol{P}_c$ is position vector of the center of the 3-d yarn model which corresponds to the center of the calculating region. Shown in Fig.4 is an image of the correlation of the voxel data of a yarn and the 3-d yarn model in the calculating region.

The 3-d yarn model h, which is called a weighting function is represented as follows:

$$h(r) = -2\exp\{-s\ r^2\} + \exp\{-t\ r^2\}, \tag{3}$$

where s and t decide the profile of the weighting function. The s and t are adjusted in such a way that a shape made from zero cross points of the weighting function fits to the yarn shape. Note that, the 3-d yarn model is weighted to reduce noise influence of the background and other yarn parts of the voxel data in consideration of a background condition that the yarn is surrounded by the background. Shown in Fig.5 is a profile of the weighting function $h(r)$, a yarn part, its center, the calculating region, and the correlation value J_3, which are described in a dimension respectively.

By changing the direction of the 3-d yarn model around its center, a value of J_3 changes. The value of J_3 become larger as the yarn part fits better in the shape made from the zero cross points of the weighting function. On the one hand, the value of J_3 is reduced significantly when the background part of the voxel data is correlated with the minus part of the weighting function because f has 1 on the background part. Therefore, when the value of J_3 is at its maximum the direction of the 3-d yarn model, that is $\boldsymbol{d}$, corresponds to the direction of the yarn in the calculating region. Consequently, the $\boldsymbol{d}$ is regarded as the direction of the yarn in the calculating region. The direction of the yarn in the region can be estimated by this 3-d yarn model correlation method.

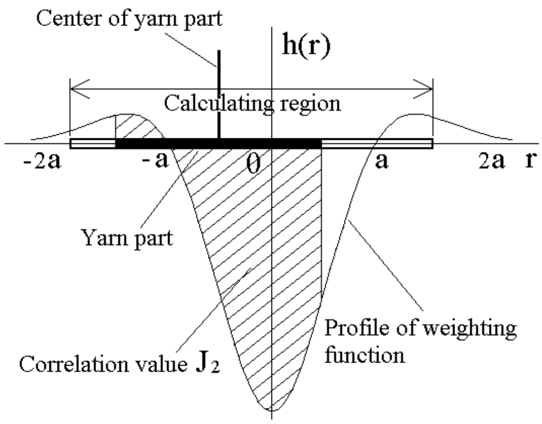

Fig. 5. Profile of the weighting function $h(r)$, a yarn part, its center, the calculating region, and the correlation value J_2, which are described in a dimension respectively

3.2. Yarn tracing by using three-dimensional yarn model correlation method

By using the 3-d yarn model correlation method a yarn is traced. The procedure is as follows. First, the calculating region in which the yarn can be regarded as straight is set by manual operation in such a way that the center of the region corresponds to a yarn core point. Then the direction of the yarn in the calculating region is estimated by the 3-d yarn model correlation method. Note that, the center of the 3-d yarn model corresponds to the center of the calculating region. Second, the region is moved along the estimated direction slightly. The center of the moved calculating region is regarded as one of the core points of the yarn. Then a direction of the yarn in the new calculating region is estimated by the 3-d yarn model correlation method again. Consequently, a yarn is tracing by repeating this procedure. As a result the sequence of the estimated core points of the yarn is obtained by this yarn tracing method. In this study, the sequence of the estimated core points of a yarn means the positional information of a yarn.

3.3. Issues of yarn tracing method

A fundamental issue of the 3-d yarn model correlation method, however, is a deformation of yarn cross-sectional shape. In this method, the correct yarn direction cannot be estimated if the yarn cross-sectional shape becomes different with a circular form which is the yarn model one. When a yarn is given an external pressure, the yarn cross-sectional shape tend to be deformed, especially at parts where yarns entwine tightly each other. Therefore, in our previous study textile fabric structures such as tight woven fabric ones cannot be analyzed. Another issue is additionally to set the calculating region for starting yarn trace by manual operation. This operation is time-consuming work and required an experience.

4. Segmenting yarn from voxel data

4.1. Three-dimensional Fiber Model Matching Method

For resolving the issue, we focus on fiber shapes, of which a yarn consists because the fiber cross-sectional shape is hardly deformed. The 3-d yarn model correlation method can be applied to fiber by adjusting the parameters, s and t in such a way that a shape made from zero cross points of the weighting function fits to the fiber shape, and the calculating region, in which a fiber can be regarded as straight. The fiber directions can be estimated using the correlating method, which is newly called three-dimensional (3-d) fiber model matching method. Additionally, focusing on fibers has another advantage that there are a lot of spaces between fibers. The space is very important for the method to estimate a fiber direction because the fiber is correlated with fiber model in consideration of a background condition that the fiber is surrounded by the background.

4.2. Yarn segmentation method

A yarn is segmented using the fiber direction estimated by the 3-d fiber model matching method as follows. First, the fiber directions at all the voxels are estimated using the 3-d fiber model matching method. Second, the voxels which have higher values of J_3 than a threshold value are selected as fiber origins to reconstruct the fibers. The threshold value is empirically determined. Then, the fiber origins are connected each other if the estimated fiber directions of voxels within a small region are most similar to each other. A product of the two fiber directions, d_i and d_j is defined as the similarity S as follows:

$$S = d_i \cdot d_j \tag{4}$$

where, d_i and d_j are fiber directions, of which magnitude are 1 respectively. The more similar the voxels are, the nearer the similarity is accordingly to 1. The fiber origins consequently reconstruct the fibers by connecting each other one after another using this procedure. Then, reconstructed fibers are bound up to yarns by clustering them using a distance which is newly defined as a dissimilarity. The dissimilarity DS of two fibers, f_i and f_j is defined as follows:

$$DS = \max_{s \in \sigma_i}\{\min_{t \in \sigma_j}\{|p_s - p_t|\}\} \tag{5}$$

where, p_s and p_t are positions of voxels, of which the fibers consist. σ_i and σ_j are sets of the points, of which the fiber consist respectively. The dissimilarity means the furthest distance between p_s and p_t. All the fibers are clustered by a threshold value of the dissimilarity from the longest fiber, which means that the fiber has most voxels. The threshold value is empirically determined. Consequently, each yarn of the textile fabric is segmented from voxel data without setting the calculating region for starting yarn trace, even if the yarns cross-section are deformed.

5. Experimental

We applied the proposed yarn segmentation method to voxel data made out of CT images of an actual textile fabric. The

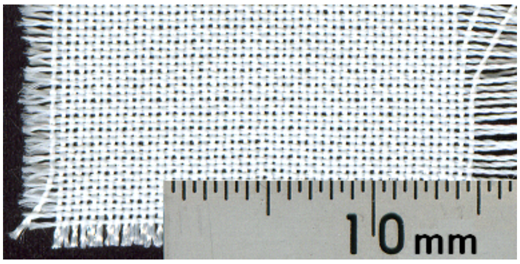

Fig. 6. Photograph of sample plain woven fabric

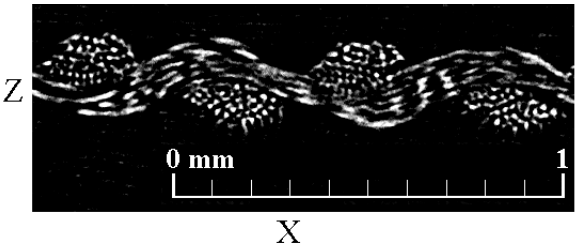

Fig. 7. CT image example of sample plain woven fabric

sample textile fabric is a plain woven fabric which is made of polyester two folded yarn, of which diameter is about 0.1mm as shown in Fig.6. The objective of this experiment is not to segment each warp and weft but each yarn of the two folded yarn. A high-resolution general purpose micro-CT system (SkyScan co. Model SkyScan-1072) is used as an imaging device, of which the resolution is about 2.7μm in this experiment. The 320 CT images are taken at about 2.7μm intervals. Shown in Fig.7 is one of the CT images, in which white particles are the fiber cross-sections. The cross-sectional shape of each two folded yarn is deformed from a circular form to an elliptical one because each yarn tightly entwines. Shown in Fig.8 is the plain woven fabric structure of the sample woven fabric reconstructed by accumulating its CT images directly.

6. Results and Discussion

Shown in Fig.9 are some of estimated fiber direction vectors. It is confirmed that the estimated directions are approximately correct in comparison with Fig.8 and Fig.9. Note that all the estimated directions of voxel are not always correct, but it is no problem to reconstruct fibers from the voxels because the wrongly estimated directions aren't connected any voxels because of the low similarity against near voxels. Shown in Fig.10 are some of reconstructed fibers by connecting the similar voxel. It is also confirmed that the reconstructed fibers are approximately in comparison with Fig.8 and Fig.10. Then, shown in Fig.11 are two of yarns, which is reconstructed by binding up the reconstructed fibers. It is confirmed that the yarns are reconstructed correctly in comparison with Fig.8 and Fig.11. In our previous study, each yarn of the two folded yarn cannot be traced because the yarn cross-sectional shape is deformed from a circular form to an elliptical one as described above. Additionally it is available for analyzing how a sample fabric is woven to express each yarn independently like Fig11. Note that each

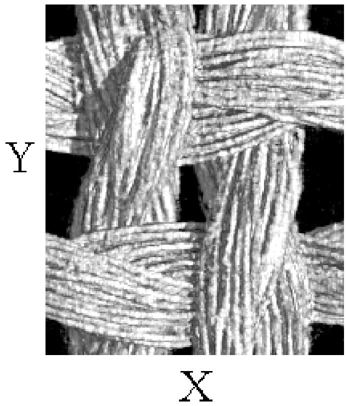

Fig. 8. Plain woven fabric structure reconstructed by accumulating its CT images directly

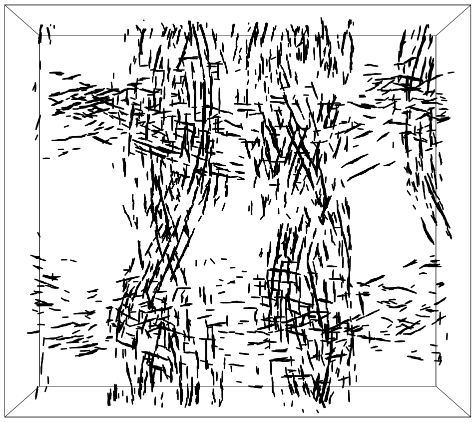

Fig. 9. Some of estimated directions of the fiber origins which have higher values of J_3 than a threshold value

yarn cannot be expressed independently by only using the CT images directly as shown in Fig.8.

7. Conclusions

In this present work, a novel method for analyzing a textile fabric structure has been proposed to segment each yarn of the textile fabric from voxel data made out of its X-ray CT images. In this method, each yarn of the textile fabric which cannot be analyzed in our previous study is segmented focusing on the fiber direction. This method has been applied to a sample plain woven fabric, which is made of polyester two folded yarn. It has confirmed that the each two folded yarn is correctly segmented by the proposed method experimentally. This result indicates that textile fabric structures including tight woven fabric ones and knit fabric ones which cannot be analyzed in previous studies can be analyzed by this method. The obtained information of segmented yarns will apply many needs including identification of the woven pattern and designs of textile fabrics in future work.

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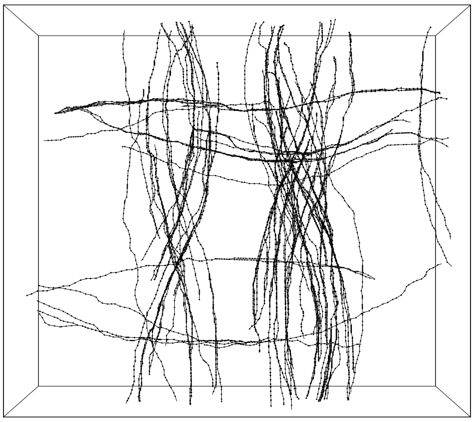

Fig. 10. Some of reconstructed fibers by connecting the similar voxel

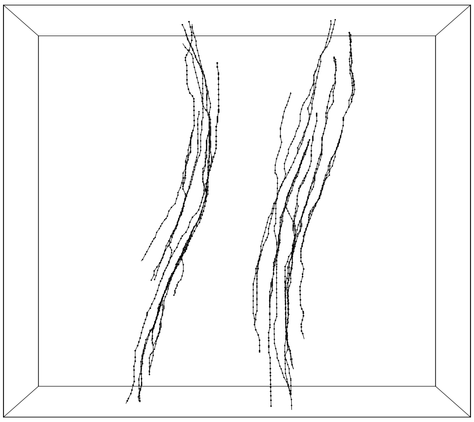

Fig. 11. two of reconstructed yarns by binding up the reconstructed fibers

of the sample textile fabrics were taken by Mr. N.Saito and Ms. E.Tamura both at TOYO Corporation.

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